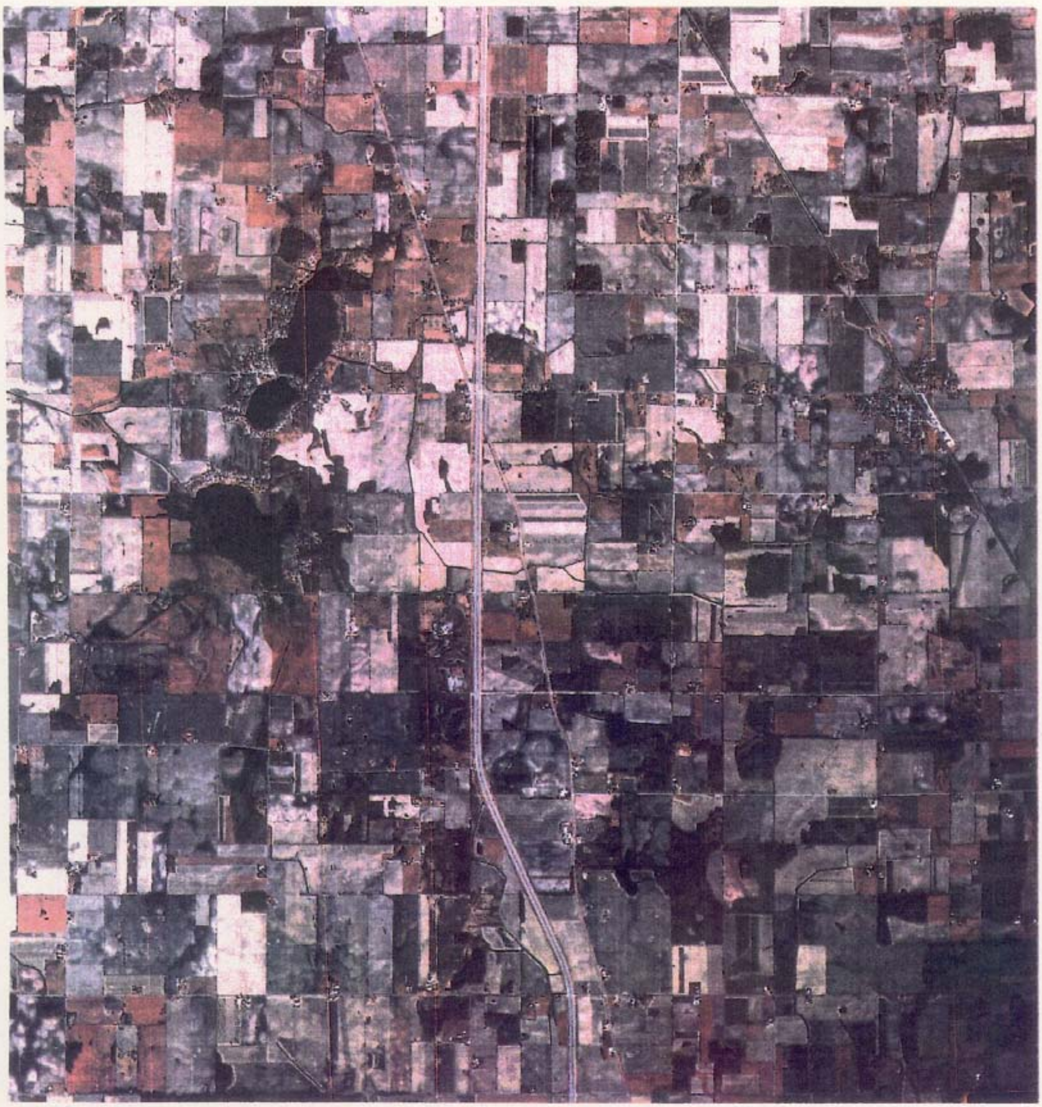
Nyona Lake...
South Mud Lake...

A Study for the Improvement, Restoration, and Protection...

1981 color infrared, aerial photograph Nyona, South Mud Lakes, and vicinity



Nyona Lake...
South Mud Lake...

A Study for the Improvement, Restoration, and Protection... of

Prepared for:

Nyona Lake Lions Club
Lake Enhancement Committee
Fulton County, Indiana

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

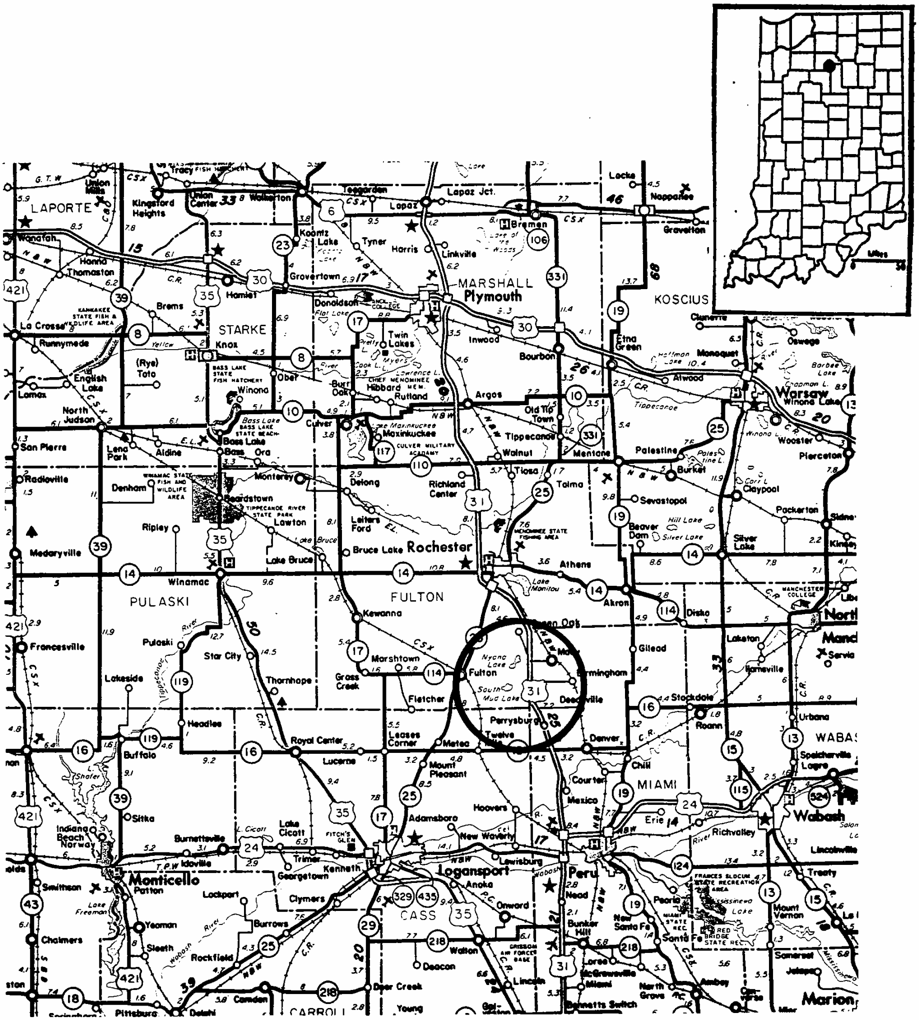
APPENDIX

TABLE OF ILLUSTRATIONS

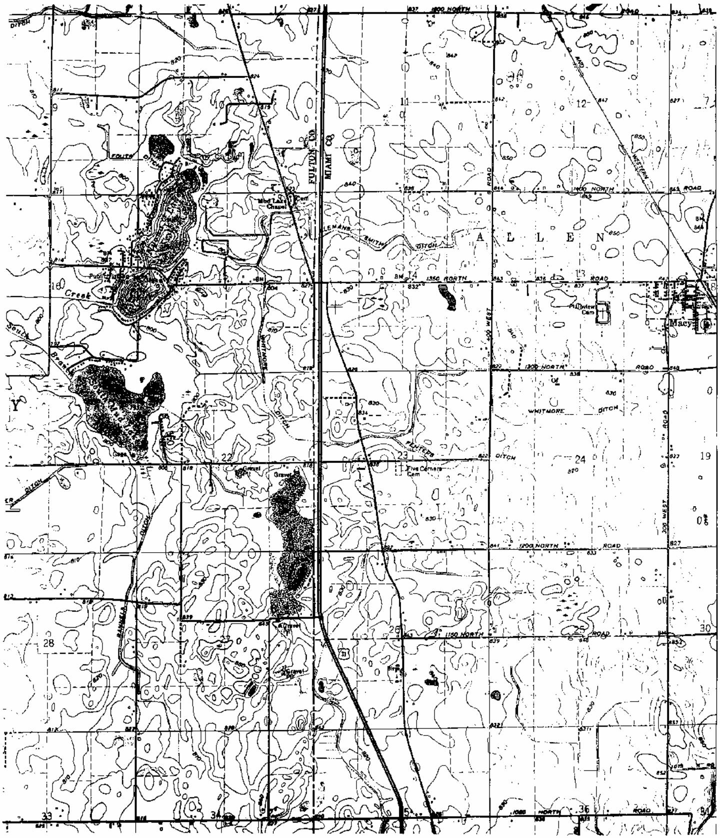
TABLE OF ILLUSTRATIONS

TABLE OF ILLUSTRATIONS

TABLE OF ILLUSTRATIONS



Regional Location Map


1200 NORTH
FULTON CO.
MIAMI CO.
Mud Lake Chapel
Cem
A L L E N
DITCH
1350 NORTH
ROAD
Public Fishing
Creek
Macy
1300 NORTH
WHITMORE
DITCH
Five Corners Cem
Gravel
1200 NORTH
1150 NORTH
300 WEST
ROAD
NORTH

Area Map

Acknowledgments/Credits

Many individuals from various agencies, interests, and expertise contributed to the preparation of this report.

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Executive Summary

EXECUTIVE SUMMARY

Nyona Lake is a eutrophic lake in Fulton County, Indiana composed of two basins. Historical data suggest that eutrophication has accelerated in the lake since at least the early 1960's when aquatic weed problems and algal blooms were noted during summer. Currently, the lake has serious weed problems in waters less than 5 feet deep, most of which are attributed to the exotic species Eurasian watermilfoil. Algal blooms dominated by blue-green algae are common during summer and the fishery is dominated on a numerical basis by the rough fish gizzard shad.

The principal contributing factors for the eutrophication of Nyona Lake have been identified as nutrients and sediments from watershed sources and delivered by ditches into the north basin of the lake. Stream borne sediment has been responsible for pronounced basin infilling of nearshore areas with some shallow depth contours increasing up to 50% in aerial extent since 1954.

It is recommended that while aquatic weed beds be left intact at the mouths of inlet ditches to serve as nutrient and sediment traps, cost effective weed control for Nyona Lake can be acheived through winter lowering of lake level by five feet. Such an action will help consolidate and oxidize nearshore sediments and may freeze reproductive structures and roots of aquatic weeds. Although species specific responses to drawdown have been noted, control of the problem species in Nyona Lake should be effective. Potential detrimental consequences of drawdown should be considered as part of any management plan including possible increased phytoplankton, winter fish kills and increased predation on young fish. Special attention should be paid to possible increased sediment nutrient release in shallow areas following macrophyte control. It is recommended that implementation of such a program of water level fluctuation be monitored by the Indiana Department of Natural Resources.

If drawdown is used as a macrophyte control at Nyona Lake, it is recommended that a mixed species assemblage of emergent macrophytes be planted at all stream mouths to act as a nutrient and sediment filter. Emergent vegetation should prove resistant to additional winter drawdowns, thus minimizing the negative impact on the stream "kidney". It is suggested that successful lake management will be hindered until watershed sediment and nutrient loading to the lake are reduced drastically.

South Mud Lake is a eutrophic lake in Fulton County, Indiana composed of a single basin. Historical data suggest that eutrophication has accelerated in the lake since at least the mid 1960's with the most pronounced biological changes taking place between 1970 and 1973 when aquatic weed problems proliferated and undesirable fish species including gizzard shad quickly increased to dominate the fish assemblage numerically. Currently, the lake has serious weed problems in waters less than 5 feet deep, most of which are attributed to the exotic species Eurasian watermilfoil. Algal blooms dominated by blue-green algae are common during summer.

The principal contributing factors for the eutrophication of South Mud Lake have been identified as nutrients and sediments from watershed sources and delivered by ditches. Of the three ditches entering the lake, Zanger Ditch clearly has had the greatest historical impact on the lake. Sediment delivered by Zanger Ditch has been responsible for pronounced basin infilling of nearshore areas with some shallow depth contours increasing up to 53% in aerial extent since 1948.

It is recommended that while forested wetlands and aquatic weed beds be left intact at the mouths of inlet ditches to serve as nutrient and sediment traps, cost effective weed control for South Mud Lake can be acheived through winter lowering of lake level by two-five feet. Such an action will help consolidate and oxidize nearshore sediments and may freeze reproductive structures and roots of aquatic weeds. Although species specific responses to drawdown have been noted, control of the problem species in South Mud Lake (Eurasian watermilfoil) should be effective. Potential detrimental consequences of drawdown should be considered as part of any management plan including possible increased phytoplankton, winter fish kills and increased predation on young fish. Special attention should be paid to possible increased sediment nutrient release in shallow areas following macrophyte control. It is recommended that implementation of such a program of water level fluctuation be monitored by the Indiana Department of Natural Resources.

If drawdown is used as a macrophyte control at South Mud Lake, it is recommended that a mixed species assemblage of emergent macrophytes be planted at all stream mouths to act as a nutrient and sediment filter. Emergent vegetation should prove resistant to additional winter drawdowns, thus minimizing the negative impact on the stream "kidney". It is suggested that successful lake management will be hindered until watershed sediment and nutrient loading to the lake are reduced drastically.

Nyona Lake 1.

NYONA LAKE

Introduction

Nyona Lake, Fulton County, is a 104 acre lake with a maximum and mean depth of 32 feet and 12.9 feet, respectively (figure page ii). Legal lake level is 793.91 feet and is controlled by a concrete dam at the outlet into Mud Creek. The south basin of Nyona Lake has no permanent inlets, while the north basin has two draining a predominately agricultural watershed. Fouts Ditch enters from the north and Whitmore Ditch enters from the east.

The present study was initiated because of lake residents concerns regarding excessive submergent weed growth, a reduced quality recreational fishery, and observation of siltation in the north basin associated with delivery of erosion products from the watershed especially during early spring rains.

The current chapter is designed to define the current water quality of Nyona Lake and to determine whether current values represent a marked decline in water quality within the historical past. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on the water quality for Nyona Lake. The second section summarizes the water quality analyses conducted as part of the present study and compares values to earlier studies. The third and final section details our sediment studies at Nyona Lake where we were interested in learning the extent of basin infilling in the historical past as well as changes in phosphorus loading to the lake. Management implications of our analysis of past and current water quality will be discussed later in this report.

Historical Water Quality

Database

A total of 12 separate studies were conducted at Nyona Lake between 1954 and 1989 for which data were available (Table 1). The United States Geological Survey constructed a bathymetric map for Nyona Lake in 1954, but collection of water quality data on the lake did not begin until 1964. The Indiana Department of Natural Resources surveyed the fish community 6 times after 1964 and in several of these surveys included data on water chemistry and macrophytes. The Indiana State Board of Health estimated bacterial numbers in the lake 5 times and visited the lake once in the mid-1970's to collect water chemistry and select biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state. No other data were found in the files of state and federal agencies or as research projects conducted by universities of the state.

Physical/Chemical Parameters

A total of thirteen physical and chemical parameters have been measured at Nyona Lake at a frequent enough intervals to be useful in delineating historical trends (Table 2). Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer, it is likely that they reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature. Thus, it is only valid to make interyear comparisons for individual months. Secchi values for May 1989 (North 5.66 feet, South 5.66 feet) were the highest transparency readings ever recorded. Unfortunately all previous readings were collected during June-August and thus can not be used for establishing intramonthly historical trends. It is normal for May values in a lake to be higher than during summer because algal populations are generally lower in late spring. The July readings for 1989 (North 3.37 feet, South 2.87) were greater, however, than recorded for any July (1964, 1970, 1973) in the historical database, and the mean for the two sampling dates of 1989 (Figure 1) was greater than values recorded on all previous occasions except August 1975. As will be discussed later in this chapter, this recent increase in water clarity may not reflect an improvement in water quality, but may result from expansion of submergent weed growth to a point that it can effectively compete with algae for nutrients in the water column. The end result would be fewer algae suspended in the water column and clearer water.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production (Table 2). With the exception of July 1964, midsummer mean oxygen values in the water column of Nyona Lake historically remained below 5.0 mg/L suggesting fairly eutrophic conditions. Mean water column values during July 1989 (North 3.37, South 2.87) were lower than recorded for any previous July suggesting a further deterioration in water quality since the early 1970's. The historical data suggest that deep water deoxygenation during summer has become worse in the past 10-15 years and has been become progressively earlier in the year.

Table 1. Chronology of Investigations at Nyona Lake

1954	United States Geological Survey. Construction of bathymetric map for Nyona Lake.
1964	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1966	Indiana State Board of Health. Bacteriological investigation at 1 sampling station.
1966	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1968	Indiana State Board of Health. Bacteriological investigation at 13 stations.
1970	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1973	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1975	Indiana State Board of Health. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
1980	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters.
1987	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1988	Indiana State Board of Health. Bacteriological investigation at 1 stations.
1989	Indiana State Board of Health. Bacteriological investigation at 2 stations.

Table 2. Historical Changes in Physical and Chemical Parameters at Nyona Lake for the Period 1964-1987.

Historical Data		July 1964	July 1970	July 1973	August 1975	June 1980	June 1987
Secchi	feet	2.5	2.5	2	5	4	2
Mean Dissolved Oxygen	mg/L	5.11	3.96	4.16	4.51	4.8	3.24
Alkalinity	mg/L as CaCO3	174	178	212		255	272
pH		7.8	8			8.2	8.5
Ca	mg/L		152				
Fe	mg/L		0.1				
K	mg/L		3				
Mg	mg/L		100				
Mn	mg/L		0.03				
Na	mg/L		5				
Cl	mg/L		15				
SO4	mg/L		50				
Total Phosphorus	mg/L						
Ortho Phosphorus	mg/L		0.2		0.12		
Nitrate-N	mg/L				0.06		
Ammonia-Nitrogen	mg/L		0.3		0.1		
Total Kjeldahl N	mg/L				1.2		
Nitrite-Nitrate	mg/L				1.1		
Chlorophyll	mg/m3						

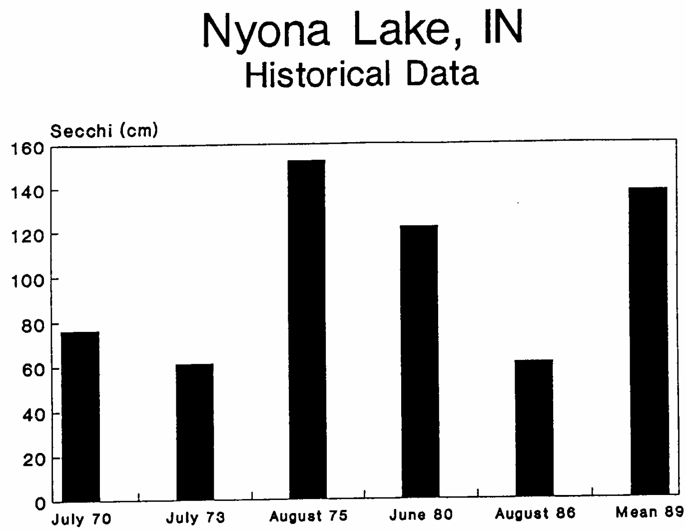


Figure 1. Historical Secchi Disk Readings in Nyona Lake for the Period 1970-1989.

A good measure of the extent of eutrophication is provided by the extent of water column anoxia in mid summer (Table 3). The historical data suggest that the water column of Nyona Lake during June normally is devoid of oxygen below a depth of 20 feet. By July, however, the anoxic layer has historically moved upward in the water column to 10 feet and remained there until fall mixing. The data for 1989 in both the north and south basins of Nyona Lake were consistent with trends established in previous investigations.

Total alkalinity, a measure of the carbonate buffering capacity of lakes, displayed a clear historical trend (Table 2, Figure 2). From a low of 174 mg/L in 1964, values increased progressively during the next 22 years to peak at 272 mg/L in 1986. The obvious source for the progressive increase in carbonate content of Nyona Lake water since 1964 is increased delivery from the watershed via soil erosion and leaching processes. It is highly unlikely that domestic sewage from the residences surrounding the lake had any appreciable impact on this parameter. As will be discussed later, total alkalinity is but one of many parameters that record the accelerating impact of agricultural practices on water quality in Nyona Lake in recent years. Mean alkalinity for the two sampling dates of 1989, however, was as low as that recorded in the late 1960's and may represent a residual effect of the drought of 1988.

Although the remaining physical and chemical parameters were sampled too infrequently to provide any historical perspective (Table 2), examination of the limited database for total phosphorus suggested a progressive reduction in water column values from 1970 to 1989 (Figure 3). It is likely that phosphorus loading to the lake has not decreased, rather nutrient uptake by the accelerated expansion of submergent macrophytes since the mid 1960's has proven effective at depleting water column phosphorus levels. No previous survey attempted to evaluate whether photosynthesis in Nyona Lake was nitrogen or phosphorus limited.

Microbiology

Mr Wesley Burden of the Fulton County Health Department supplied microbiological data from 4 surveys conducted by the Indiana State Board of Health between 1966 and 1989 (Table 4). Please note that these surveys were meant to identify pollution sources and thus were conducted in the vicinity of suspected violators. Only once (October 1968) did total coliform bacteria levels exceed state standards, while both fecal coliform and fecal strep levels have been within standards on all dates analyzed.

Table 3. Historical Records of Water Column Anoxia in Nyona Lake, IN

Observation	Initial Depth of <1 mg/L Dissolved Oxygen
June:	
1980	20 feet
1987	20 feet
July:	
1964	10 feet
1970	10 feet
1973	10 feet
August:	
1975	10 feet

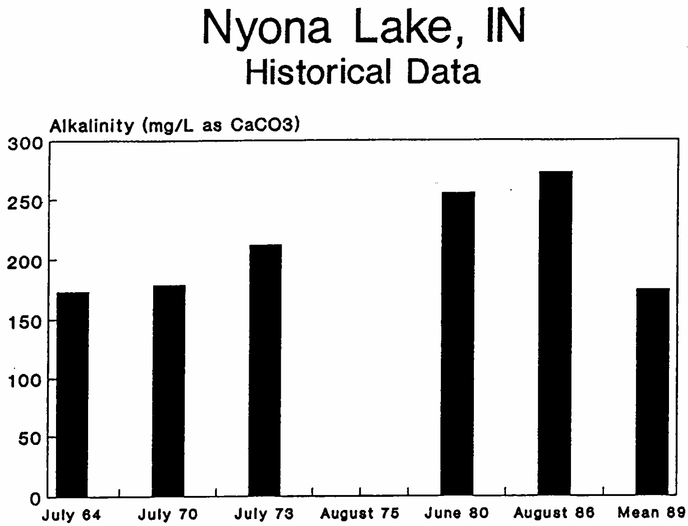


Figure 2. Historical Alkalinity Readings in Nyona Lake for the Period 1964-1989.

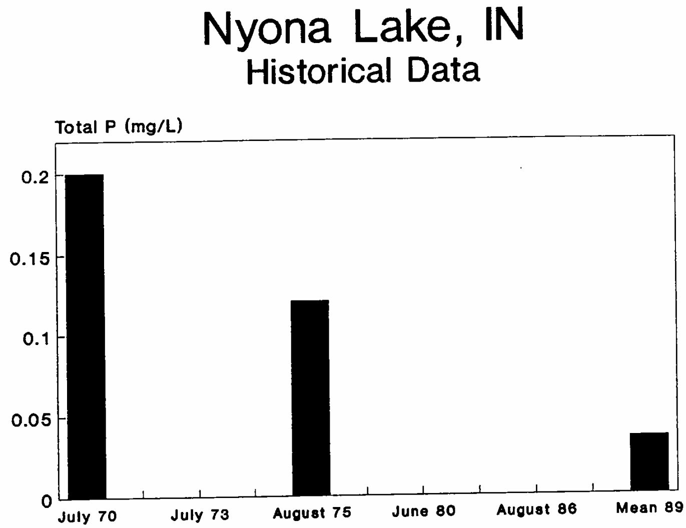


Figure 3. Historical Total Phosphorus Concentrations in Nyona Lake for the Period 1970-1989.

Table 4. Compilation of Past Microbiological Testing at Nyona Lake.

		Coliform Bacteria mpn/100mL			Fecal Coliform mpn/100 mL		Fecal Strep/100 mL	
Date	# Stations Sampled	Mean	Maximum	# Stations >1000/100 mL	Maximum	# Stations >400/100 mL	Maximum	# Station >100/mL
18 July 1966	1		40					
23 October 1968	13	392	1000	1				
21 March 1988	1				<10		<10	
4 May 1989	2	10	20					

Phytoplankton

Phytoplankton samples have been collected only once as part of the Indiana Board of Health survey in the summer of 1975. Total algal abundance was 22,000 units/mL in surface waters (0-5 feet) and 38,000 units/mL near the thermocline (10-15 feet). Although representatives of five algal groups were identified (Table 5), dominant algae in Nyona Lake were blue-green algae. Lyngbya, a genus of blue-green algae characteristic of eutrophic lakes, was reported as the dominant genus, but the abundance of individual algal taxa was not given. As this information came from unpublished notes from ISBH files and no details were given on whether algal counts were based on the abundance of cells or "individuals", we have used the term "units" as an undefined expression. During their 1964 survey, the DNR observed an algal bloom on the lake and noted that according to residents, such blooms were common throughout summer in most years.

Macrophytes

The macrophyte (aquatic weed) community was examined five times during Indiana Department of Natural Resources fish surveys conducted between 1964 and 1987. The greatest diversity of taxa recorded has always been for the submergent community (Table 6). Several pondweed species were recorded and shared dominance with chara, watermilfoil, and coontail. The remaining communities, emergents, floating-leaved, and free floating, historically have been represented by six, two, and one taxa, respectively. It is interesting to note that the species composition of the entire weed community appears to have changed little between 1964 and 1987.

As early as 1964, the DNR noted that aquatic weeds were abundant in Nyona Lake. The greatest extent of submergent macrophytes was noted in the south basin, while that of emergent macrophytes was found in the north basin. Coontail was the dominant submergent followed by chara and curly-leaved pondweed. Coontail formed a dense band around the entire lake between 5 and 10 feet water depth and was paralleled by a band of chara in the 1-5 foot water depth zone. It was felt that macrophytes were sparse at greater than 10 feet water depth. In order to improve fish habitat, it was suggested that the lake residents establish a macrophyte control program for those sections of the lake less than 10 feet deep. A cost estimate for such a program was given at $2,000 for chemicals alone.

Thick nearshore beds of chara were considered a probem in 1966, but it was noted that recent dredging along the shore had eliminated some weed problems. Both coontail and

Table 5. Phytoplankton Composition of Nyona Lake August 1975

Algal Group	Genus
Diatoms	Cyclotella
	Fragilaria
	Meridion
	Synedra
Greens	Chlorella
	Microspora
	Pandorina
	Pediastrum
	Scenedesmus
Blue-Greens	Anacystis
	Aphanizomenon
	Lyngbya
Dinoflagellates	Ceratium
	Dinobryon
Euglenophytes	Euglena

Table 6. Species Composition of the Macrophyte Community of Nyona Lake for the Period 1964-1987.

Species	Common Name	1964	1966	1970	1973	1987
SUBMERGENTS:						
Ceratophyllum demersum	coontail	x	x	x	x	x
Chara spp.	chara	x	x	x	x	
Elodea canadensis	elodea	x				
Myriophyllum spp.	water milfoil					x
Najas flexilis	bushy pondweed	x	x	x		
Najas quadalupensis	southern naiad				x	
Pithophora						x
Potomogeton amplifolius	pondweed	x				
Potomogeton crispus	curly pondweed	x	x	x	x	x
Potomogeton nodosus	american pondweed					x
Potomogeton pectinatus	sago pondweed	x		x	x	
Potomogeton pusilis	pondweed	x				
Vallisneria americana	eel grass	x		x	x	
Vallisneria neotropicalis	eel grass					x
EMERGENTS:						
Decodon verticillatus	water willow	x				
Pontederia cordata	pickerelweed	x				
Sagittaria latifolia	arrowhead	x		x	x	
Scirpus americanus	bulrush			x	x	
Scirpus validus	softstem bulrush	x				
Typha latifolia	common cattail	x		x	x	x
FLOATING LEAVED:						
Nuphar advena	spatterdock	x	x	x	x	x
Nymphaea tuberosa	waterlily	x	x	x	x	x
FREE FLOATING:						
Lemna minor	duckweed	x				x

chara were considered management problems in 1970, when the DNR again suggested initiation of a chemical control program. At the time macrophytes were estimated to cover approximately 20% of the total lake surface area. Macrophytes continued to cover 20% of lake surface in 1973, but an ongoing chemical control program appeared to be effective for management of chara in nearshore areas. It was recommended that a similar chemical program for management of coontail be considered.

Fish

The Indiana Department of Natural Resources surveyed the fish community of Nyona Lake six times between 1964 and 1987. For the following discussion, it must be remembered that historical changes in the fish community are considered indicative of trends and that interyear differences in the percentage contribution of each taxon reflect to some unknown degree interyear variability in sampling methodology. A listing of the individual species caught and the contribution of each to total fish abundance caught during DNR surveys from 1964-1987 is presented in Table 7.

Although a total of 26 taxa have been identified from Nyona Lake, bluegill, gizzard shad, largemouth bass, redear, and white sucker have been the dominant taxa for at least the past 25 years. Since at least 1980, gizzard shad clearly has been the dominant fish on a weight basis (30-37% of total fish weight) followed by white sucker (18-20%), redear (13-15%), and spotted gar (6-10%). Although bluegill and largemouth bass were numerically important, they contributed only 4-6% and 2-8%, respectively, of total fish weight in Nyona Lake. The remaining fish taxa have not represented over 10% of total fish weight in the lake since at least 1980 (Table 8).

The 1964 DNR fish survey was conducted because the Nyona Lake Fish and Game Club reported that fishing was poor and requested assistance. Following the survey, the DNR noted that longear sunfish abundance was excessive and likely contributed to poor bluegill success. It was also suggested that both bluegill and largemouth bass populations could be improved if aquatic weed growth was controlled in the lake.

The 1964 DNR report also noted that bluegill fishing in the lake was considered to have been good prior to about 1949 but had steadily declined since then. In addition, northern pike were considered abundant in 1949 but were absent in 1964. Attempts at maintaining a good recreational fishery were undertaken throughout the 1950's via stockings of bluegill (943 in 1951, 600 in 1954), crappie (2500 in 1955), largemouth bass (340 in 1954, 900 in 1955, 1138 in

Table 7. Importance of Individual Fish Species Expressed as a Percent of Total Fish Abundance for DNR Surveys at Nyona Lake.

	1964	1966	1970	1973	1980	198
Black Bullhead						0.
Black Crappie	0.2		1.1	3	0.2	0.
Bluegill	21.6	60	28.7	19.3	26.7	12.
Brook Silversides		1.8				0.
Brown Bullhead	0.7	0.1	2.4	1.2	1.6	0.
Carpsucker		0.1				
Carp	0.1	0.8	0.2			0.
Channel Catfish				0.1		0.
Gizzard Shad	10.5	15.3	42.4	49.6	24.5	4
Golden Shiner			0.8	0.3	2	0.
Grass Pickeral	0.2	0.5				
Hybrid Sunfish	0.7		0.2			
Lake Chubsucker	0.4					
Largemouth Bass	5	5.2	3.9	2.1	5.8	4.
Longear Sunfish	26.7	6	0.8	0.9		
Northern Pike			1.1	0.1	0.2	0.
Pumpkinseed	9.7	0.5	0.2	0.8	0.4	0.
Quillback			0.6	0.5	0.4	
Redear	10.1	0.1	1.3		17.3	14.
Spotted Gar	0.3	0.1	2.4	1.1	1.6	3.
Spotted Sucker	0.5	1.2	0.8	1.2	1	0.
Warmouth	5.9	1.5	0.2	0.1	2	0.
White Crappie			1.1	6.6	1.6	
White Sucker	0.6	4.4	2.4	10.7	8	6.
Yellow Bullhead	0.8	0.5	0.2	0.1		
Yellow Perch	6	1.5	1.9	2.1	6.6	14.

Table 8. Importance of Individual Fish Species Expressed as a Percent of Total Fish Weight for DNR Surveys at Nyona Lake.

	1980	1987
Black Bullhead		0.10
Black Crappie	0.30	0.20
Bluegill	6.70	4.50
Brown Bullhead	3.30	2.00
Carp		0.60
Channel Catfish		0.90
Gizzard Shad	30.20	37.20
Golden Shiner	0.90	
Largemouth Bass	8.00	2.60
Northern Pike	0.90	0.20
Pumpkinseed	0.02	0.20
Quillback	2.70	
Redear	15.80	13.50
Spotted Gar	6.90	10.00
Spotted Sucker	0.80	0.90
Warmouth	0.50	0.20
White Crappie	1.80	
White Sucker	18.70	20.60
Yellow Perch	2.40	6.30

1958), and redear sunfish (500 in 1956). The 1964 DNR report did not feel that additional stockings could improve the fishery without removal of redear.

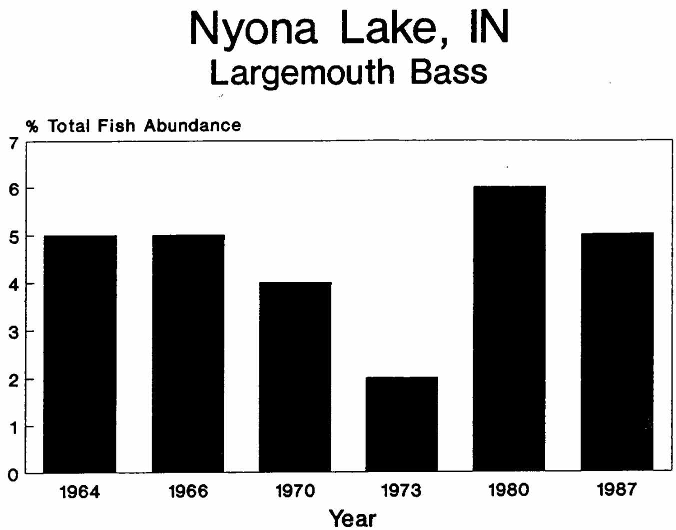
While bluegills less than 4 inches and below average condition comprised 21% of total fish abundance in the 1964 survey, the percentage contribution (60%) of total fish abundance, size (mostly greater than 4 inches) and condition (plump) improved markedly by the 1966 survey. The bass population changed little during the same two year period. The proportion of undesirable sunfish (longear, pumpkinseed, warmouth) declined from 44% in 1964 to 8% in 1966, but the rough fish population (mainly gizzard shad) was elevated over 1964 levels.

Gizzard shad was such a major fish community component by 1970 (40% of total fish abundance) that the DNR recommended initiation of a selective removal program for this species using rotenone. Such a selective eradication program was conducted in September 1971 after which fingerling largemouth bass were stocked to the lake. In spite of such a management scheme, gizzard shad abundance by 1973 was 7% greater than that reported in the 1970 survey. On a positive note, black and white crappies, although only minor elements in previous surveys, had increased to almost 10% of total fish abundance.

The large rough fish populations (gizzard shad, white sucker) continued to be of concern following the 1980 survey when it was recommended by DNR that fingerling northern pike be stocked during the fall of 1982 to increase predation intensity on the undesirable taxa. Stocking with northern pike was delayed until August 1986, when 550 fish 8.5 inches in length were introduced. Only two of these stocked fish were caught during the DNR survey of 1987 indicating either poor survival in the lake or the fact that the fish were stocked at a small size. Additional surveys are required to evaluate fully the success of the 1986 northern pike stocking.

Changes in the percentage contribution of select species to total fish abundance as recorded in the DNR surveys of 1964-1987 are summarized in Figure 4. With the exception of a short period of reduced abundance during the early 1970's, largemouth bass has consistently made up 5-6% of total fish abundance in Nyona Lake. Although bluegill peaked at 60% of total fish abundance in 1966, its representation for the period 1964-1984 was fairly steady at 20-30%. The 1987 value (12%), however, was the lowest percentage representation recorded in the past 25 years.

The most worrisome fishery change in Nyona Lake has been the pronounced increase in gizzard shad that took place between 1966 and 1970 (Figure 4). The shad increase appears



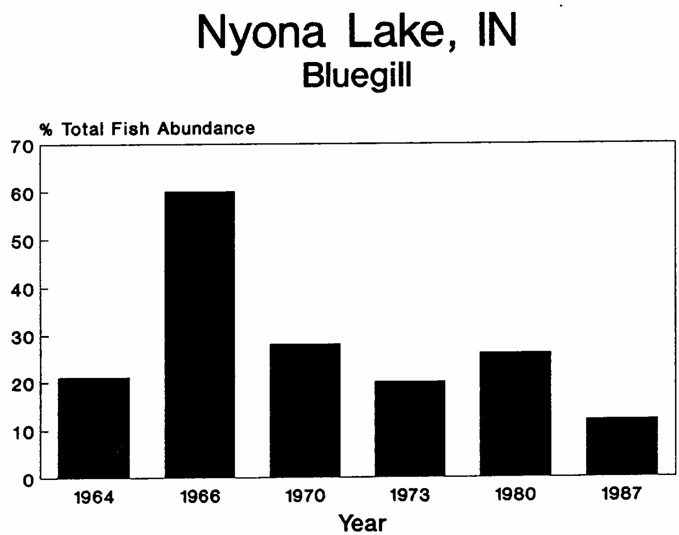
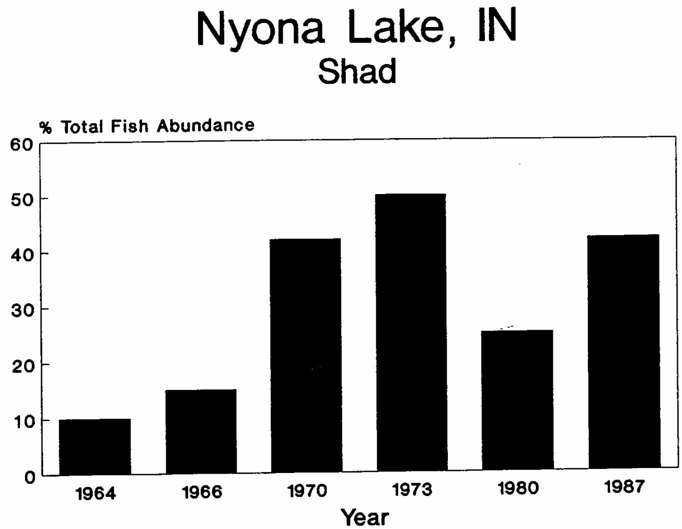


Figure 4. Changes in the Percentage Contribution of Select Species to Total Fish Abundance in Nyona Lake for the Period 1964-1987.



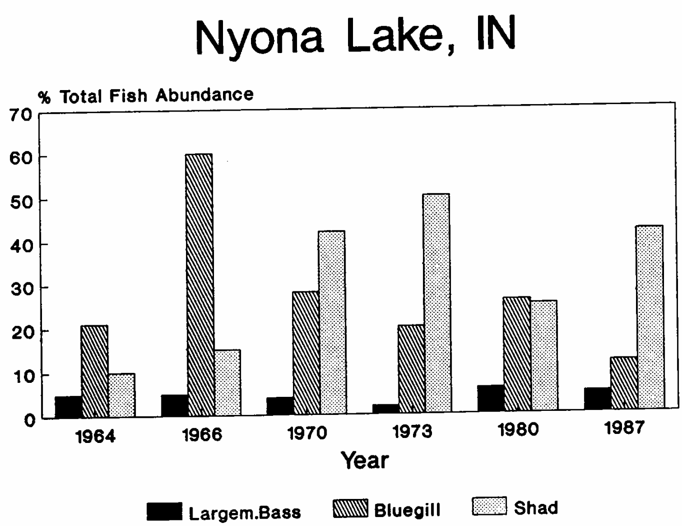


Figure 4. (Continued)

to have taken place concurrently with the period of major expansion of submergent macrophytes. Such high shad levels pose potential management problems in that once established, this species promotes phytoplankton dominance through its differential digestion of other algal taxa, elevated predation on large cladoceran zooplankton, and enhanced nutrient cycling for phytoplankton utilization (Crisman and Kennedy 1982, Crisman and Beaver 1988, 1990). Such a sharp increase in shad suggests that the eutrophication of Nyona Lake increased markedly between 1966 and 1970.

Current Water Quality

Introduction

Water quality parameters were collected during 1989 on 25 May and 8 July. A single sampling station was established in each of the north and south basins of Nyona Lake (Figure 5). Both stations were located in the area of deepest water as close to the center of each basin as possible. Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc and a Licor photometer. Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column where a Kemmerer bottle was used to collect water at each meter of the water column. All analyses were performed in certified laboratories according to EPA techniques (EPA-600/14-79-020, Methods for Chemical Analysis of Water and Wastes, Revised March 1983). Data for physical and chemical parameters for individual basins during the 1989 survey are presented in Table 9.

Physical/Chemical Parameters

Temperature. Water column profiles clearly demonstrated that both the north and south basins were thermally stratified during May 1989 (Figure 6) with the thermocline in both basins being between three and four meters depth. The July pattern was quite similar except that the thermocline of both basins was lower (4-5 meters) in the water column (Figure 7).

Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the

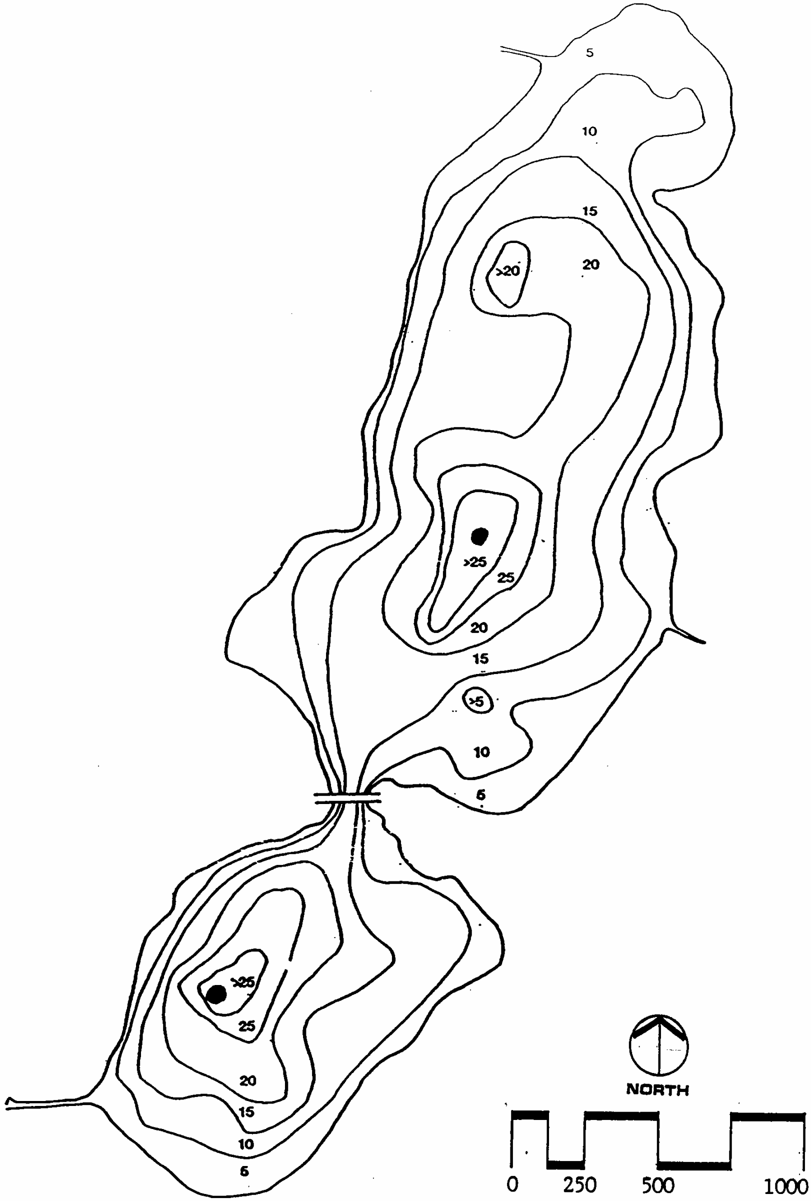
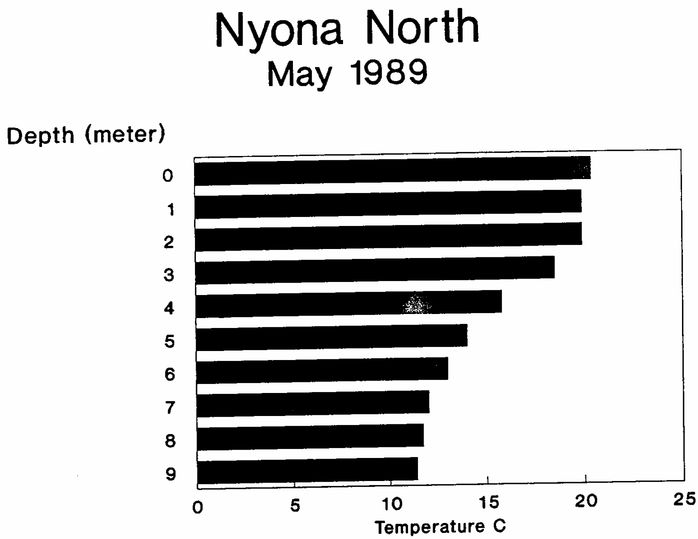


Figure 5. Water Quality Sampling Stations in Nyona Lake for 1989.

Table 9. Physical and Chemical Parameters for the 1989 Survey of Nyona Lake.

		25 May 1989		8 July 1989	
		North	South	North	South
Secchi	feet	5.66	5.66	3.37	2.87
Mean Dissolved Oxygen	mg/L	5.73	4.44	3.54	6.7
Ammonia	mg/L				0.6
Total Kjeldahl N	mg/L	3	5	7	12
Nitrite-Nitrate	mg/L	6	4.1	12	5.9
Total Phosphorus	mg/L	0.15	0.08	0.07	0.05
Ortho Phosphorus	mg/L	0.03	0.03	0.04	0.02
Conductivity	umho/cm	505	550	510	490
Alkalinity	mg/L	174	170	170	169
Chlorophyll	mg/m3	4.56	3.08	19.5	17.8



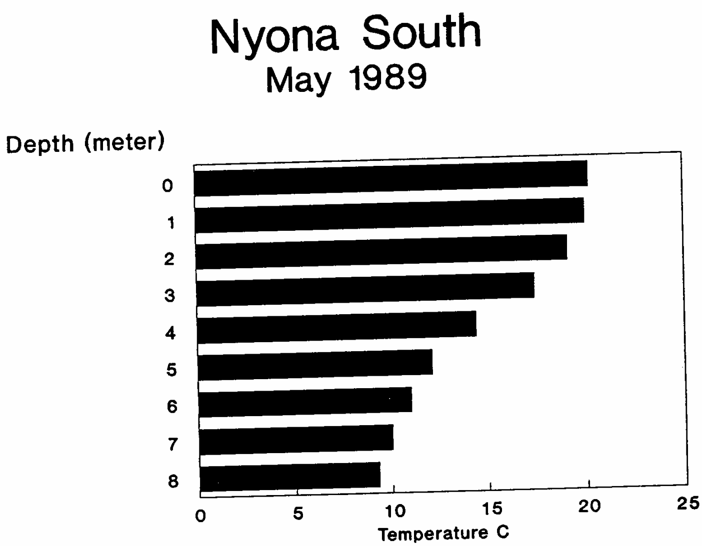
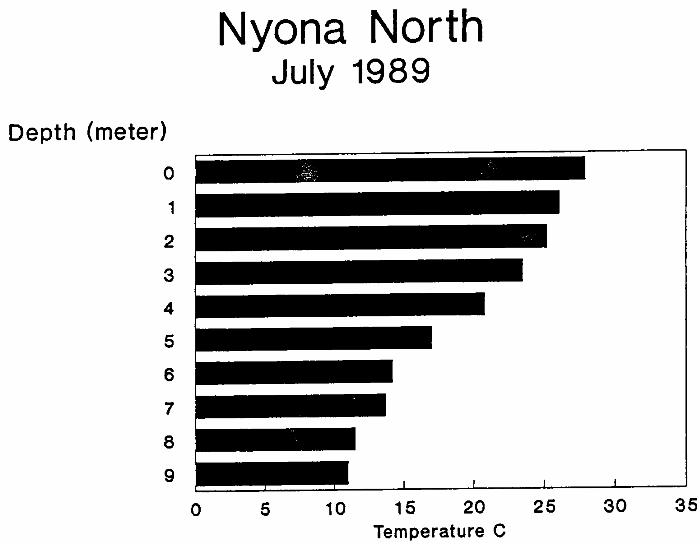


Figure 6. Water Column Temperature Profiles for the North and South Basins of Nyona Lake During May 1989.



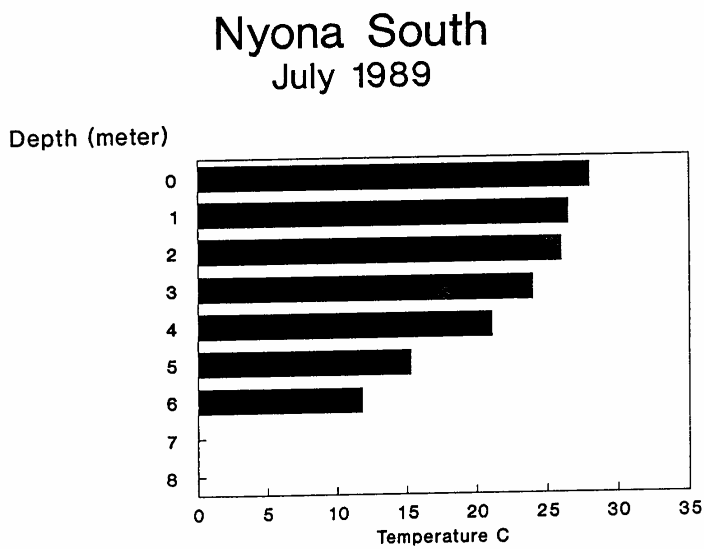


Figure 7. Water Column Temperature Profiles for the North and South Basins of Nyona Lake During July 1989.

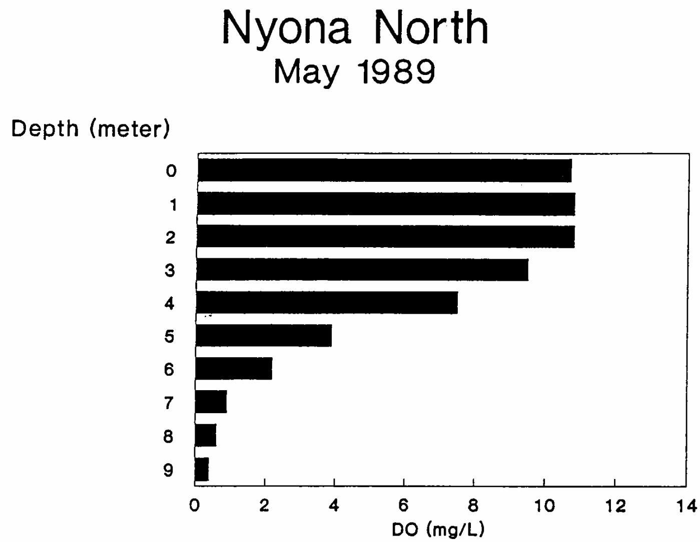
bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

The lower portion of the water column (hypolimnion) of both the north and south basins displayed pronounced deoxygenation during May 1989 (Figure 8). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). Thus, even early in the stratified period of summer, both basins were displaying symptoms of severe eutrophication.

Water column deoxygenation of both basins was even more pronounced during July (Figure 9). While the north and south basins were essentially completely anoxic below 6 and 5 meters, respectively, during May, this zone of essentially zero oxygen moved progressively higher in the water column throughout the summer. By July, the bottom of the oxygenated portion of the north and south basins extended only to a depth of 3 meters.

When expressed as a mean for the entire water column, dissolved oxygen during May was lower in the south basin, while during July the north basin was lower (Figure 10). Mean oxygen in the north basin decreased from May to July reflecting progressive deoxygenation of the hypolimnion due to decomposition of phytoplankton settling out of the water column. The marked increase in mean oxygen in the south basin during the same period, however, suggests that daytime oxygen evolution via photosynthesis from phytoplankton and the extensive macrophyte zone in the upper portion of the water column is sufficient to offset the extreme deoxygenation found in profundal waters when calculating water column means. Water column oxygen values undoubtedly decline sharply even in surface waters at nite when plants are no longer photosynthetic.

Historically, Nyona Lake has displayed severe deoxygenation of the water column below 10 feet (3 meters) depth during July (Table 3) and mean oxygen values for the water column at 3.96-5.11 mg/L (Table 2). Comparable data were recorded for 1989 with the exception of a higher water column mean in the south basin (Table 9). Thus, it appears that while serious midsummer oxygen depletion is to be expected in Nyona Lake, the severity of this condition has changed little since at least 1964.



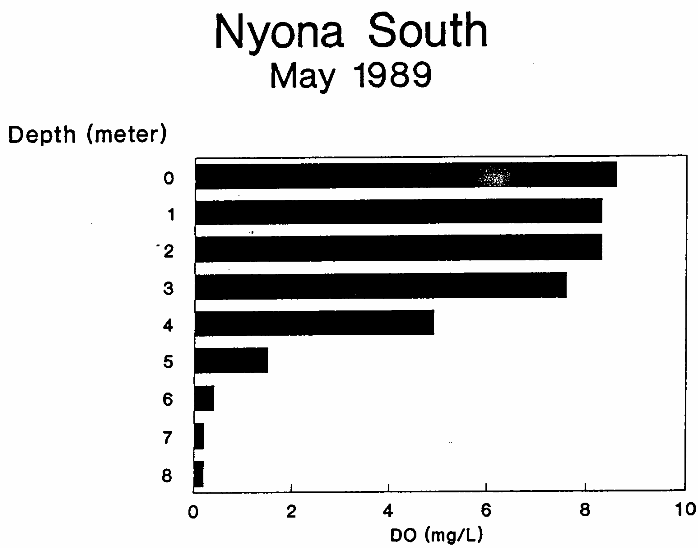


Figure 8. Dissolved Oxygen Profiles for the North and South Basins of Nyona Lake During May 1989.

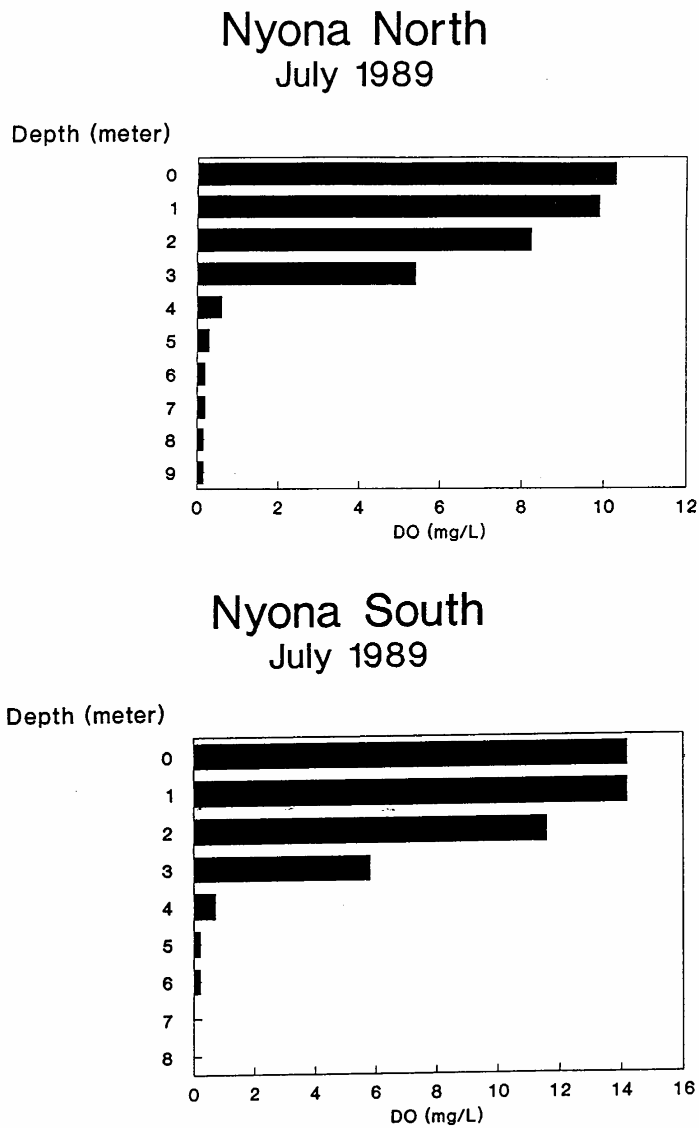
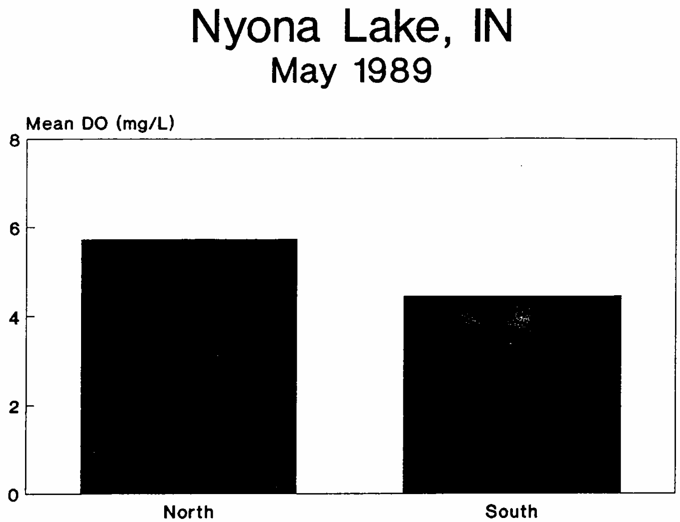


Figure 9. Dissolved Oxygen Profiles for the North and South Basins of Nyona Lake During July 1989.



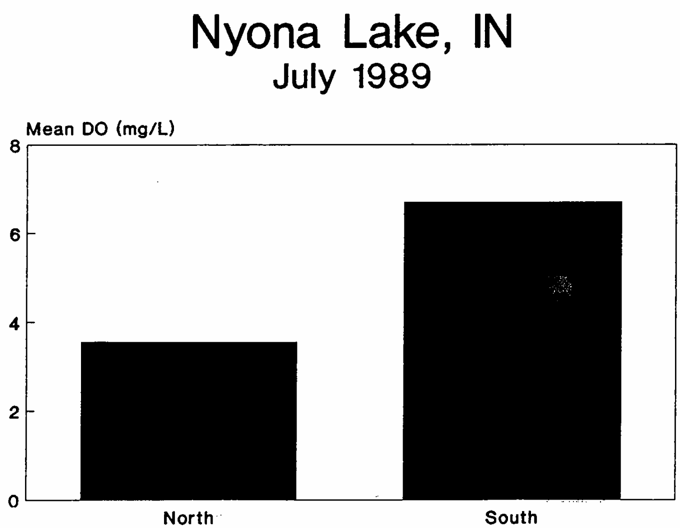


Figure 10. Mean Oxygen Values for the Water Column of the North and South Basins of Nyona Lake During May and July 1989.

Secchi Disc and Photometer Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae suspended in the water column to block light transmission. Thus, the shallower the Secchi depth during midsummer, the more productive (eutrophic) a lake is presumed to be. The Secchi depth was comparable in both basins (5.66 feet or 173 cm) during May 1989 (Figure 11). By July, Secchi transparency had decreased in both basins with the north (3.37 feet) being slightly clearer than the south (2.87 feet). Such a decline in Secchi values in midsummer is expected in highly eutrophic lakes as phytoplankton abundance increases in response to increasing temperature and reaches levels that have a marked effect on light transmission in the water column. The July 1989 values are slightly better than the 2-2.5 feet recorded during July in previous surveys (Table 2). On the basis of Secchi data alone, the trophic state of Nyona Lake appears to have changed little since at least 1964.

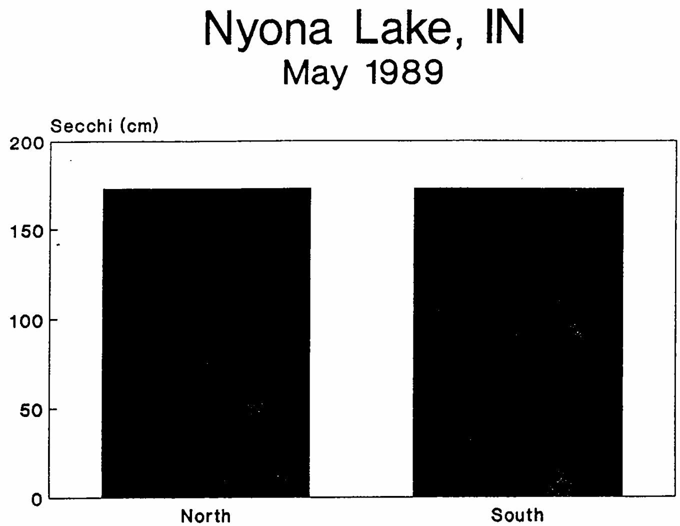
A Licor photometer was used on both sampling dates to estimate the depth of the photic layer in the north basin of Nyona Lake. During May and July of 1989, the 1% compensation point for light was calculated as 15.34 feet and 7.21 feet, respectively. Photometer data were normally included in the ISBH statewide lake survey of 1975, but were omitted at Nyona Lake because of overcast conditions.

Ammonia. Ammonia was below detection limits in both the north and south basins of Nyona Lake during May 1989, and was detectable only in the south basin during July (Table 9). The only previous measurement of this parameter was in 1975 when a value of 1.2 mg/L was recorded (Table 2).

Nitrite-Nitrate. Values for this parameter in both basins during May 1989 were lower than recorded in July when those of the north basin were double and those of the south basin were 50% greater than May (Table 9). During both months values were greater in the north basin. Historical data are totally lacking for this parameter.

Kjeldahl Nitrogen. Values for Kjeldahl nitrogen in both basins during May 1989 were approximately half those recorded in July (Table 9, Figure 12). The north basin displayed greater values than the south during both sampling events of 1989 suggesting that the former basin is somewhat more eutrophic. All 1989 values (range 3-4 mg/L) exceeded the only historical value (1.1 mg/L in 1975) for this parameter (Table 2).

Total Phosphorus. Although total phosphorus concentrations were consistently higher in the north basin in 1989, July values in both basins were lower than recorded in May (Table 9, Figure 13). The decline noted in both



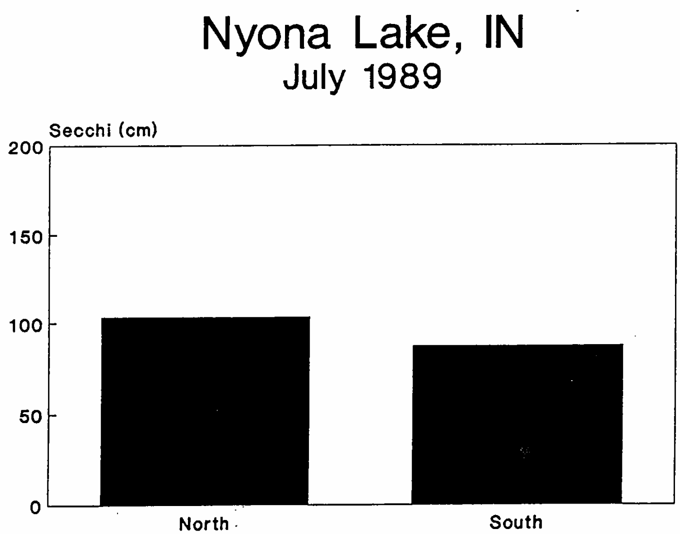
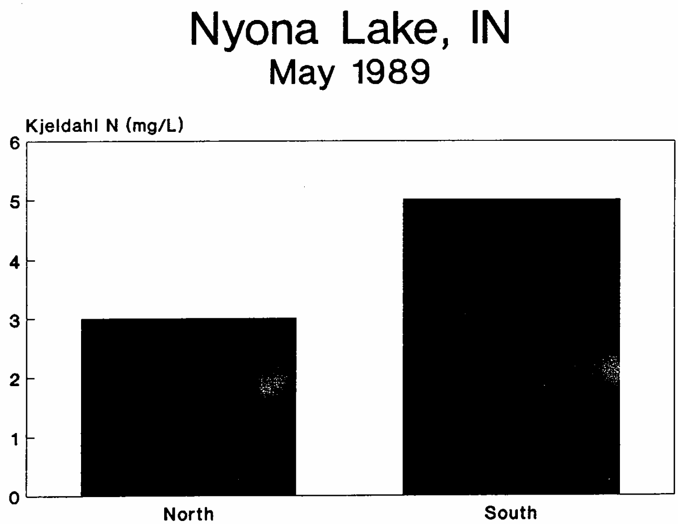


Figure 11. Secchi Disk Transparency for the North and South Basins of Nyona Lake During May and July 1989.



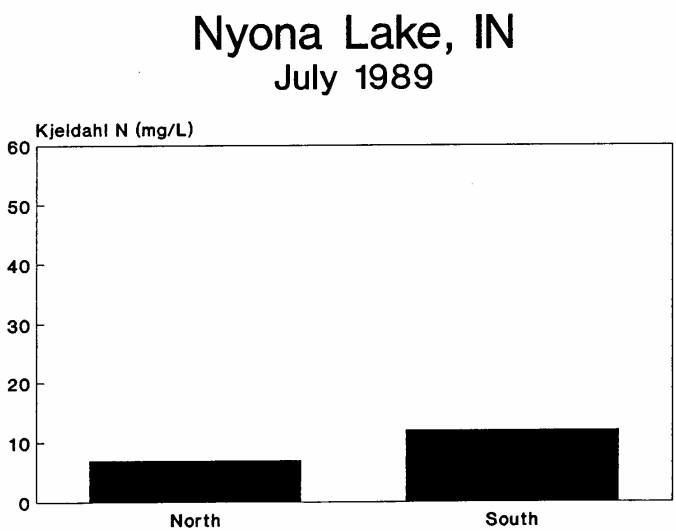
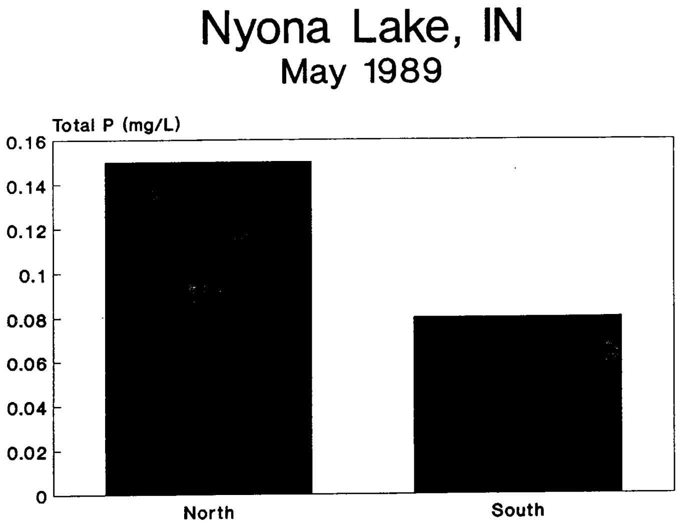


Figure 12. Kjeldahl Nitrogen Concentrations for the North and South Basins of Nyona Lake During May and July 1989.



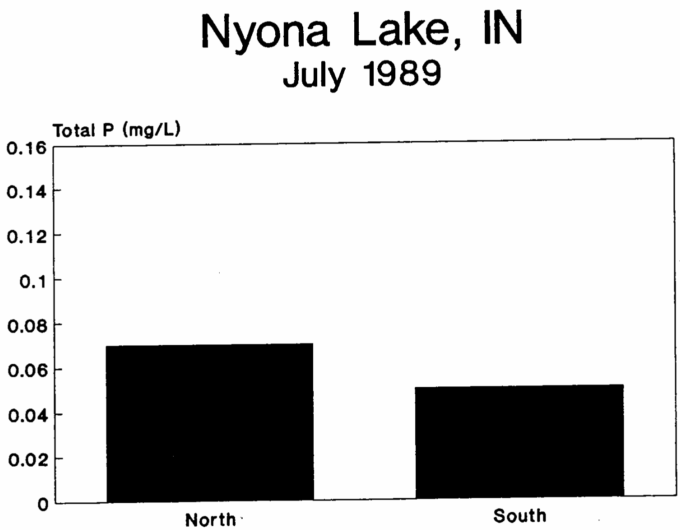


Figure 13. Total Phosphorus Concentrations for the North and South Basins of Nyona Lake During May and July 1989.

basins during July is not unexpected. Algal and weed production should be maximal during midsummer, thus scavenging phosphorus from the water column for plant growth. In addition, phosphorus in such thermally stratified basins would be expected to be trapped in the lower portions of the water column as algae sink and decompose.

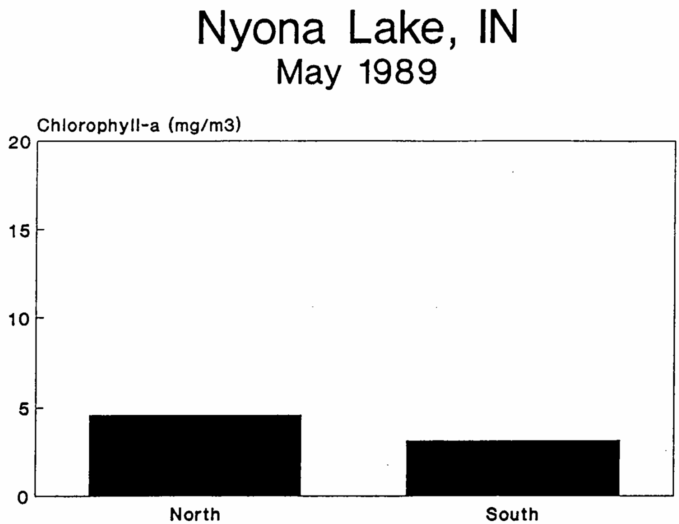
With the exception of May in the north basin (.15 mg/L), all total phosphorus values for 1989 were lower than recorded in either 1970 (0.2 mg/L) or 1975 (0.12 mg/L) (Table 2). While it is tempting to suggest that total phosphorus concentrations for 1989 appear to be somewhat lower that noted in earlier surveys, it is important to note, however, that water column concentrations of phosphorus are somewhat misleading estimates of trophic state. It is entirely possible that total phosphorus loading to a lake could have increased markedly between years, while water column values decreased. In lakes such as Nyona, which have experienced a pronounced increase in weeds, the phosphorus that is entering the system can be effectively trapped by the weed mass and actually decrease in the water column through effective competition with algae for this essential nutrient (Crisman 1986).

Ortho Phosphorus. Ortho phosphorus concentrations were identical in both basins during May 1989 (0.03 mg/L), but increased in the north (.04) and decreased in the south (0.02) during July (Table 9). All 1989 values were slightly lower than reported in 1975 (0.06 mg/L), the only other time that ortho phosphorus has been measured (Table 2).

Conductivity. No clear trend was noted in conductivity during 1989 (Table 9). While values increased slightly in the north basin between May and July (505 to 510 umho/cm), those of the south basin declined moderately (550 to 490 umho/cm). No historical data for this parameter were available for comparison.

Alkalinity. Total alkalinity in both the north and south basins decreased slightly between May and July 1989 (Table 9). The 1989 total alkalinity values (169-174 mg/L) were similar to the 1964 value (174 mg/L) but were markedly lower than the 178-272 mg/L reported for 1970-1987 lake surveys. Alkalinity is indicative of the amount of carbonate rich material dissolved in the lake water. As most of this carbonate enters the lake via watershed runoff, the data are suggestive that watershed runoff during 1989 may have been lower than many of the immediately preceeding years.

Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll values in both basins of Nyona Lake increased sharply between May (4.5, 3.1 mg/m^3) and July (19.5, 17.8 mg/m^3) 1989 (Table 9, Figure 14). The north basin displayed higher values than the south basin for



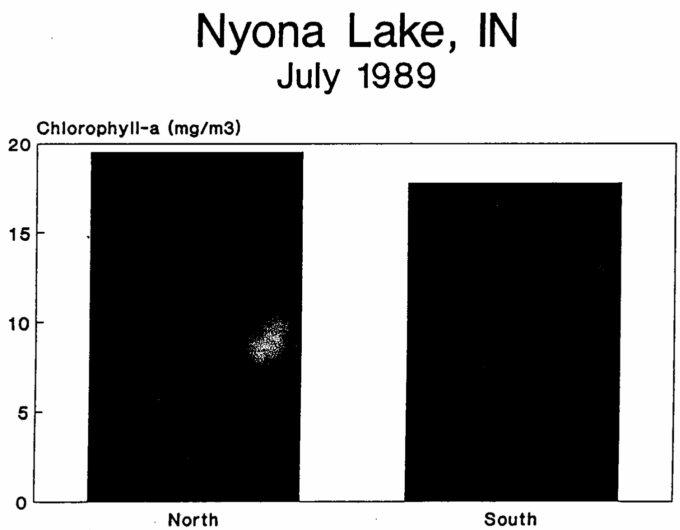


Figure 14. Chlorophyll Concentrations for the North and South Basins of Nyona Lake During May and July 1989.

both sampling events of 1989. Historical data for chlorophyll were unavailable for comparison with the 1989 database. In general, however, values from Nyona Lake in 1989 generally were within the range exhibited by mesotrophic and eutrophic lakes.

ISBH Trophic State Index

Mr Harold BonHomme of the Indiana State Board of Health devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined. The Indiana Department of Environmental Management (1986) updated the database and published the most recent form of the index.

The 1975 eutrophication index for Nyona Lake was calculated by the Indiana State Board of Health as 54, thus assigning the lake to the category of poorest water quality, class III. In the current survey, we have calculated the eutrophication index from parameter means for the two sampling dates of 1989. Calculation of the index was as follows:

Parameter and Range		1989 Value	Eutrophy Pts.
I	Total Phosphorus 0.06-0.19 ppm	0.11	3
II	Soluble Phosphorus 0.04-0.05 ppm	0.035	2
III	Organic Nitrogen 2.0 ppm or more	5.00	4
IV	Nitrate 2.0 ppm or more	6.0	4
V	Ammonia At least 0.3 ppm	Not Detected	0
VI	Dissolved Oxygen % Saturation @ 5 feet 115-119%	115	1

VII	Dissolved Oxygen % water col. with at least 0.1 ppm 76-100%	78	0
VIII	Light Penetration Secchi Disc Five feet or under	4.51	6
IX	Light Transmission Photocell: % light @ 3 feet 0-30%	24	4
X	Total Plankton per mL		
	Vertical tow from 5 feet		
	More than 10,000/mL	23,000	10
	Blue-green dominance	Yes	5
	Five foot tow including beginning of thermocline		
	30,000/mL or more	42,000	10
	Blue-green dominance	Yes	5
	Greater than 100,000/mL	No	0
	1989 Eutrophication Index		54

The eutrophication index for 1989 was calculated as 54. While the 1975 phytoplankton assemblage was dominated by Lyngbya, the 1989 midsummer assemblage was dominanted by Oscillatoria with Anacystis and Anabaena as the principal subdominants.

The fact that the eutrophication index values for 1975 and 1989 were identical likely does not reflect stable water quality conditions for the past 14 years. In fact, it is likely that water quality has worsened because such a eutrophication index is an estimate of the water column conditions in open water, and like all indices, does not include the extent and productivity of aquatic weeds. Historical evidence suggests that the extent of aquatic weeds in Nyona Lake has been expanding over at least the last decade. Expanding weed abundance is often associated with reduced nutrient and algal abundance in open water areas as the vegetated littoral zone successfully competes with open water phytoplankton for nutrients (Canfield et al. 1983). The fact that the eutrophication index indicates steady water quality during the past 14 years in spite of an increase in aquatic weeds suggests that there has been a pronounced increase in nutrient loading to Nyona Lake since 1975.

Stream Monitoring

> According to a Nonpoint Source Assessment Report, 1989, by the Indiana Department of Environmental Management, nonpoint source pollution, specifically sediments and nutrients from non-irrigated agricultural land is the primary threat to fisheries, wildlife production and the overall water quality in both Nyona and South Mud Lakes...

Methods

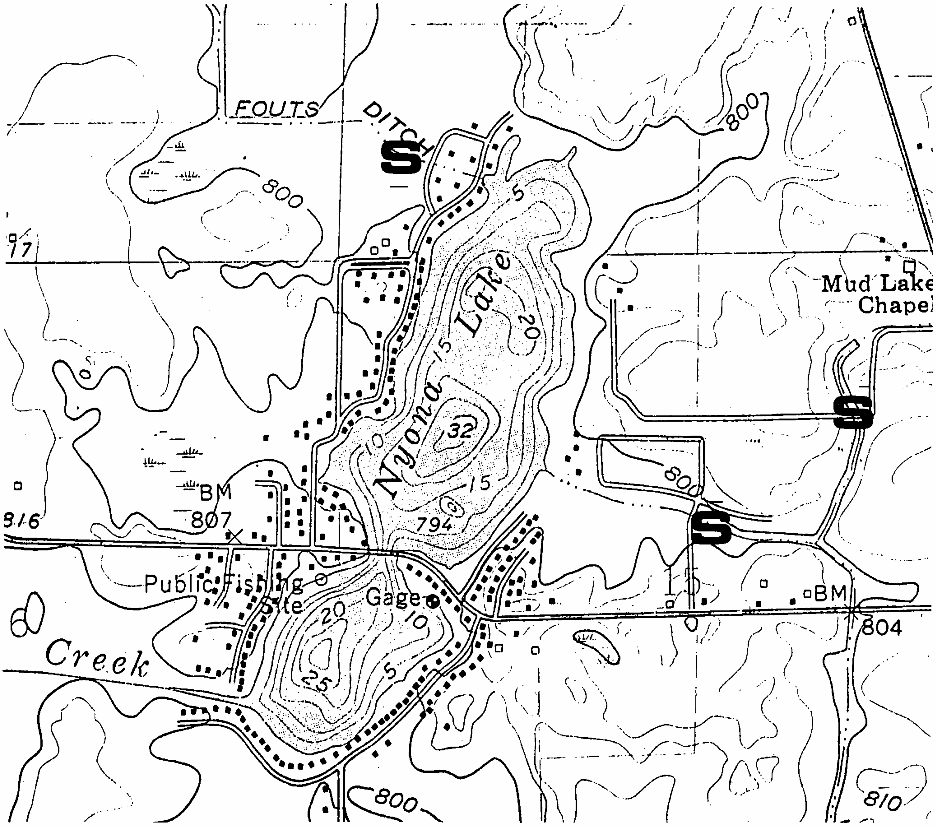
At each station, two, 1-liter water samples were collected from the upper 15 cm of the water column. Water samples were analyzed for: calcium carbonate alkalinity, specific conductivity, pH, total nitrogen, total phosphorus and color. In addition to water quality measurements, stream flow was calculated using a General Oceanics mechanical flowmeter and a visual survey was conducted of stream and basin characteristics.

Stream Chemistry

Water chemistry data were collected on 17 March 1989 for three streams in the Nyona Lake watershed: Martin-Whitmore Ditch, Clemans-Smith Ditch, and Fouts Ditch (Figure 15A). The Martin-Whitmore Ditch drains the eastern portion of the Nyona Lake watershed and enters the north basin along the eastern shore through a dredged canal. The area drained is rolling terrain with both cultivated and pasture usage. The sampling site for this stream was below the junction with the Clemans-Smith Ditch at the County Road 350E bridge.

The Clemans-Smith Ditch drains the northeastern portion of the Nyona Lake watershed, a relatively open area characterized by short pasture. This ditch joins the Martin-Whitmore Ditch before entering the north basin along the eastern shore. Samples were collected near Mud Lake Chapel where the road crosses the creek. The final inlet stream to Nyona Lake is Fouts Ditch which drains the northwestern portion of the watershed and enters the north basin at the north end. This portion of the watershed has extensive areas that are relatively flat, poorly drained and wooded. Upland areas are currently under cultivation. Water samples for Fouts Ditch were collected immediately upstream from the inlet into Nyona Lake.

Stream flow at the time of sample collection ranged from .22 cfs for Martin-Whitmore Ditch to 1.66 cfs for Fouts Ditch (Figure 15). The Clemans-Smith Ditch flow (1.338 cfs) was similar to that of the Fouts Ditch. The discharge for all three sites was considered normal for mid March.



Stream Monitoring Stations, Nyona Lake.

(Figure 15A)

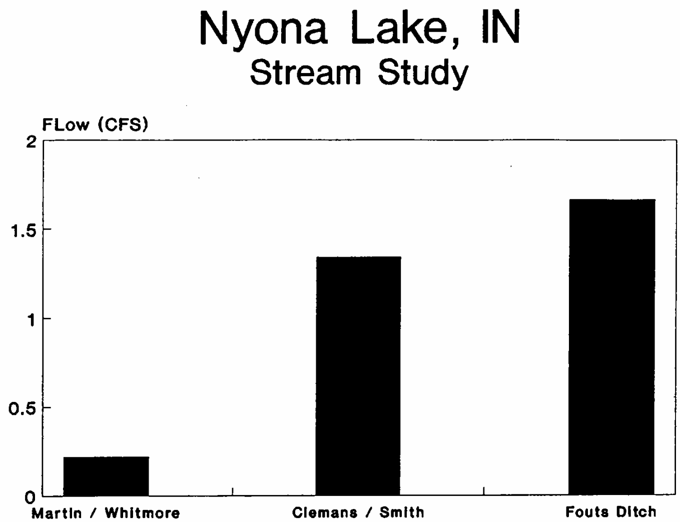


Figure 15. Flow in Three Ditches Draining the Nyona Lake Watershed For 17 March 1989.

All three streams had slightly acidic pH (Figure 16) with the lowest value (6.5) noted in the stream (Fouts Ditch) displaying the highest velocity flow. Alkalinity (Figure 17) ranged from 189 to 223 mg/L with the highest value recorded at the lowest flow site (Martin-Whitmore Ditch). Stream values were slightly higher than the 169-174 mg/L reported in Nyona Lake during May and July 1989. Conductivity (Figure 18) also displayed little variability between stream stations and ranged from 1,500 to 2,000 umho/cm.

Two forms of nutrients were measured at all stream stations. Nitrite/nitrate nitrogen ranged from 2.41 mg/L in Martin-Whitmore Ditch to 3.71 mg/L in Clemans-Smith Ditch (Figure 19). Total phosphorus (Figure 20) ranged from .06 mg/L (Clemans-Smith Ditch) to .14 mg/L (Fouts Ditch). The rank ordering of the streams for total phosphorus was roughly the opposite noted for nitrogen and appeared not to be strongly linked with stream flow characteristics. Total phosphorus values for the stream sites were similar to the .05-.15 mg/L reported for Nyona Lake during 1989 as part of the present survey. Finally, total suspended solids (TSS) ranged from 8-24 ppm (Figure 21) with the lowest values reported from the stream having the greatest velocity of flow (Fouts Ditch).

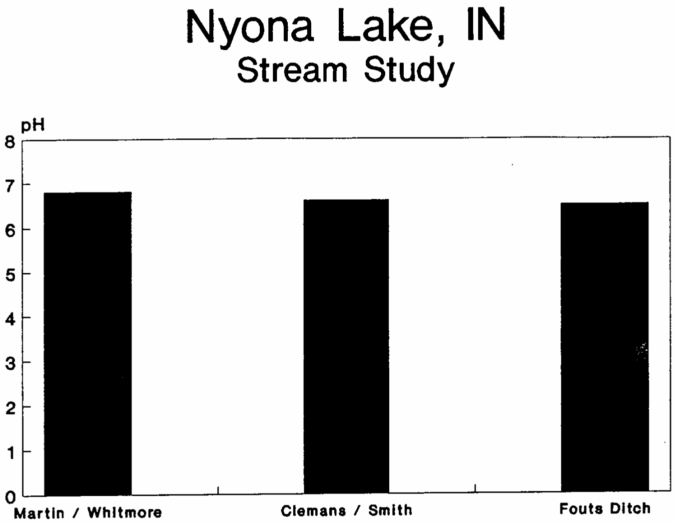


Figure 16. pH Values for Three Ditches Draining the Nyona Lake Watershed for 17 March 1989.

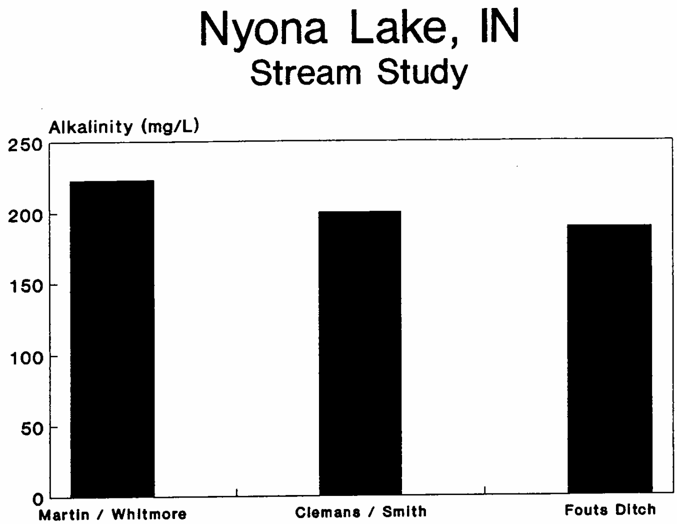


Figure 17. Alkalinity Values for Three Ditches Draining the Nuona Lake Watershed for 17 March 1989.

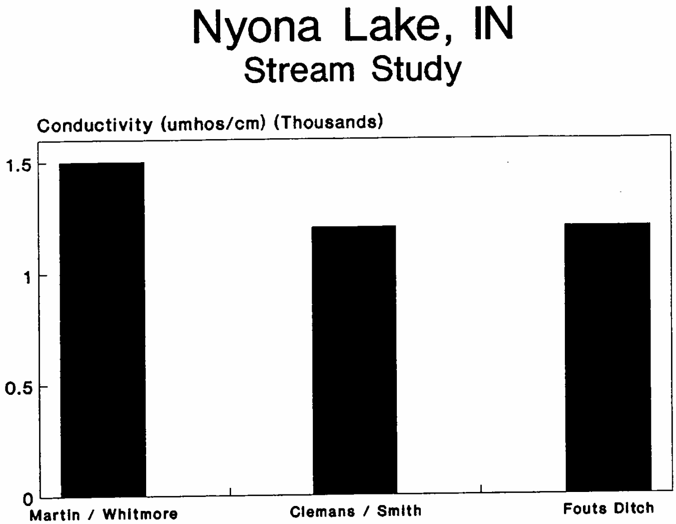


Figure 18. Conductivity Values for Three Ditches Draining the Nyona Lake Watershed for 17 March 1989.

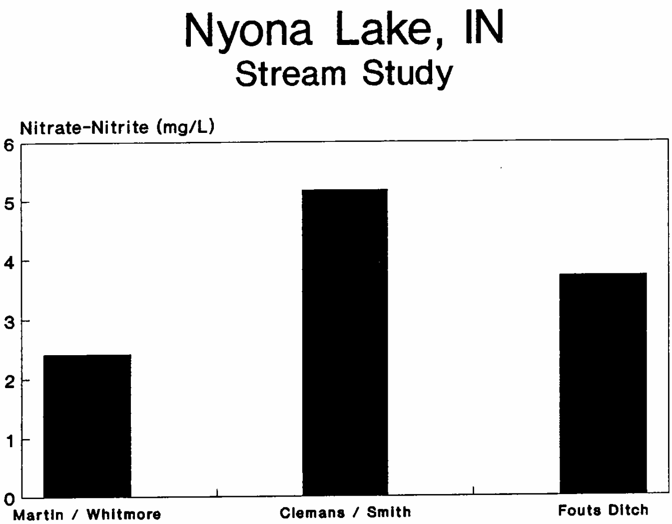


Figure 19. Nitrite/Nitrate Values for Three Ditches Draining the Nyona Lake Watershed for 17 March 1989.

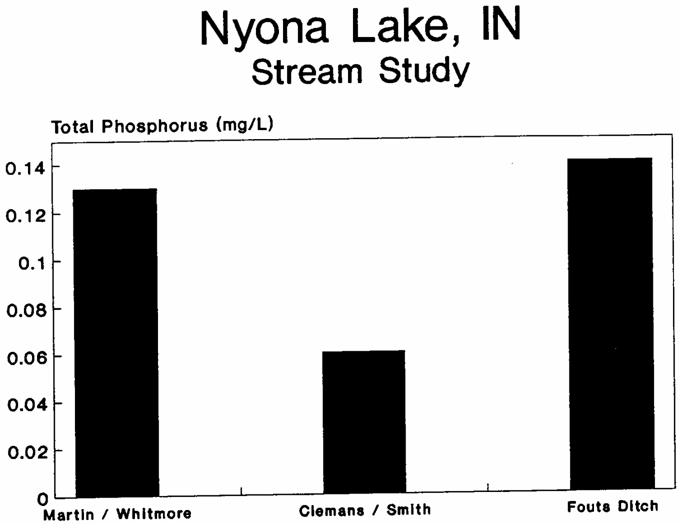


Figure 20. Total Phosphorus Values for Three Ditches Draining the Nyona Lake Watershed for 17 March 1989.

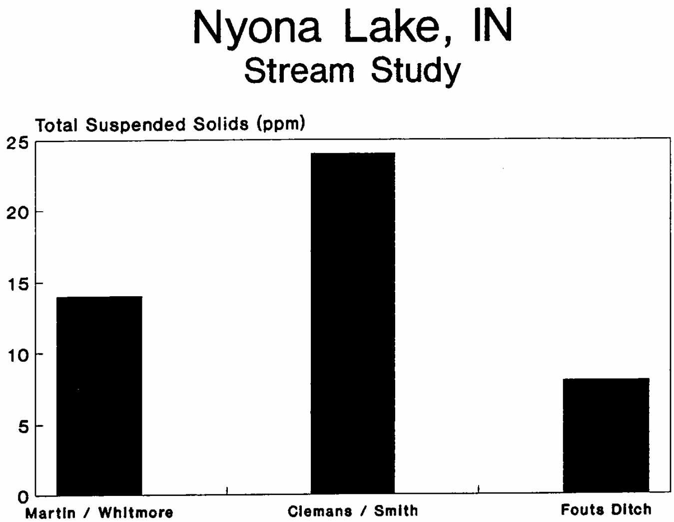


Figure 21. Total Suspended Solids Values for Three Ditches Draining the Nyona Lake Watershed for 17 March 1989.

Microbiology

Water samples for fecal coliform analysis were collected from both the north and south basins of Nyona Lake in conjunction with the May and July 1989 water quality investigations. Samples were analyzed within eight hours of collection. The analyses followed the state approved membrane filter procedure and counts have been expressed as most probable numbers (mpn), a standard way of estimating bacterial numbers. Concentrations of fecal coliform bacteria in the north and south basins for 25 May were 9 and 6 mpn/100 mL of water, respectively. Bacteria levels were slightly higher on 8 July with the north basin (14 mpn/100 mL of water) continuing to be greater than the south basin (10 mpn/100 mL of water). All bacteria counts at Nyona Lake during 1989 were well within state standards. It is felt that there is not a serious fecal contamination problem in Nyona Lake.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic weeds in both the north and south basins of Nyona Lake. A total of 29 transects spanning the width of the north and south basins were used as the data base. The plant survey was conducted in July 1989 and thus represents midsummer plant extents. Plant biovolume is defined as the percent of the water column at a given location in the lake that is filled with plant biomass. Thus, it is a measure of the extent of weed infestation throughout the lake system.

The distribution of plant biovolume in the entire Nyona Lake system is presented in Figure 22. This figure demonstrates the extremely patchy distribution of plants in the lake. A much more informative way of looking at the data is to plot biovolume in increments of 20% water column infestation (Figure 23). The nearshore areas of both basins were considered 100% infested with weeds in 1989. The maximum extent of this area was considerably greater in the north than south basin. The northeastern corner of the north basin and the south end of the south basin were so weeded that it was nearly impossible to get a motor boat to the shore.

The extent of the 80% plant infestion zone was smaller

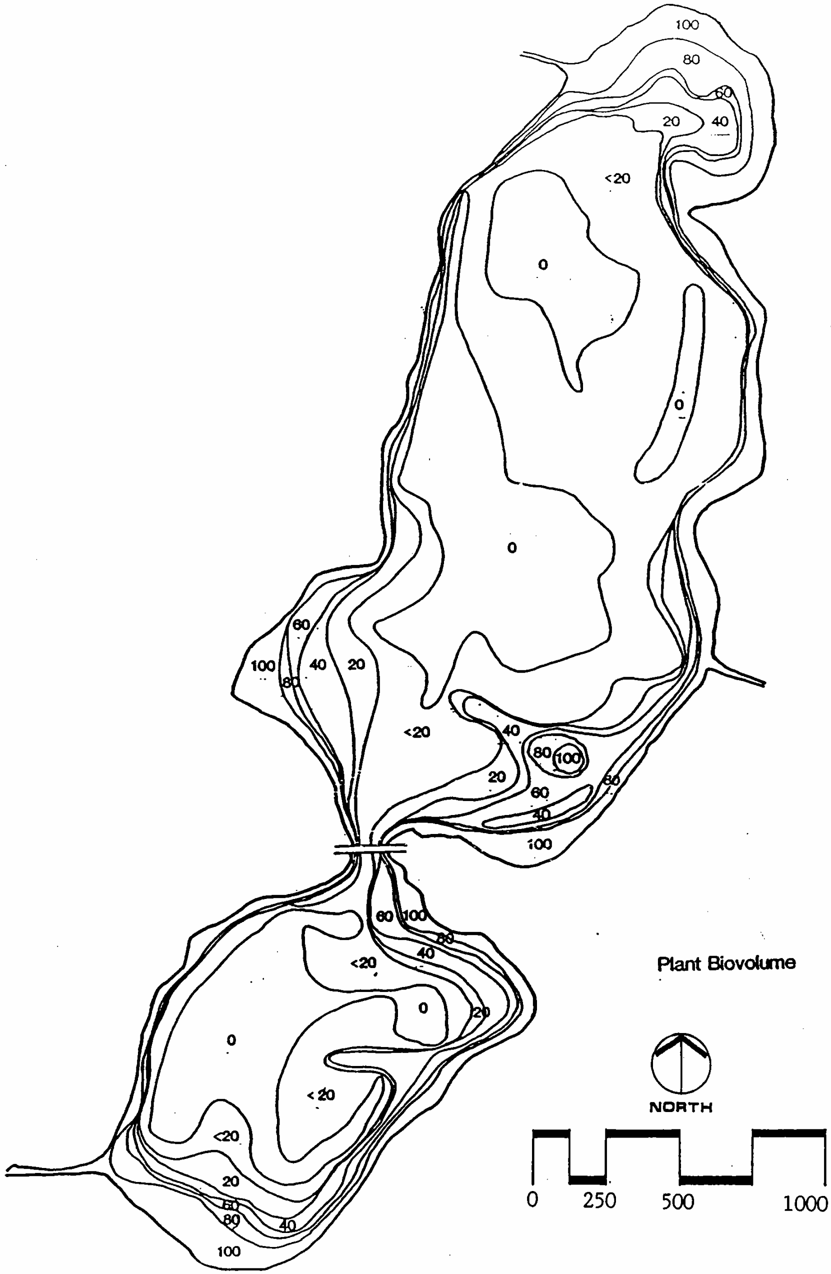


Figure 22. Distribution of Aquatic Weed Biovolume in Nyona Lake for 1989.

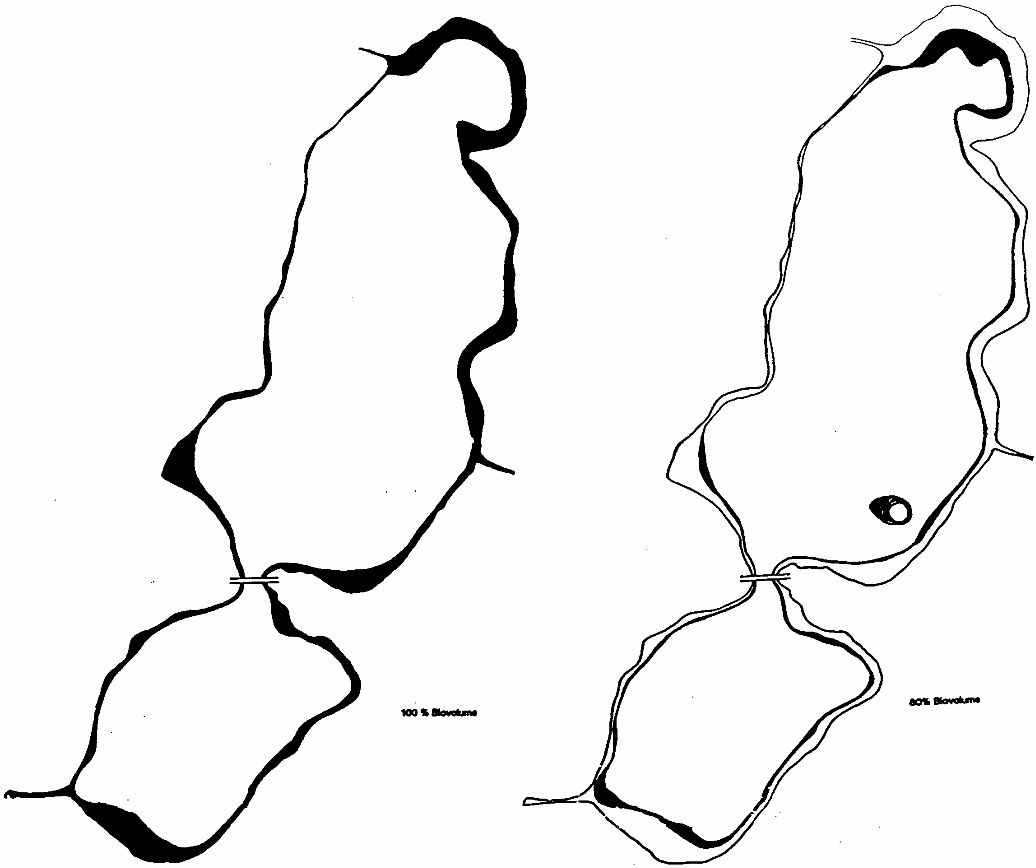


Figure 23. Plant Biovolume at Nyona Lake in Increments of 20% Water Column Infestation.

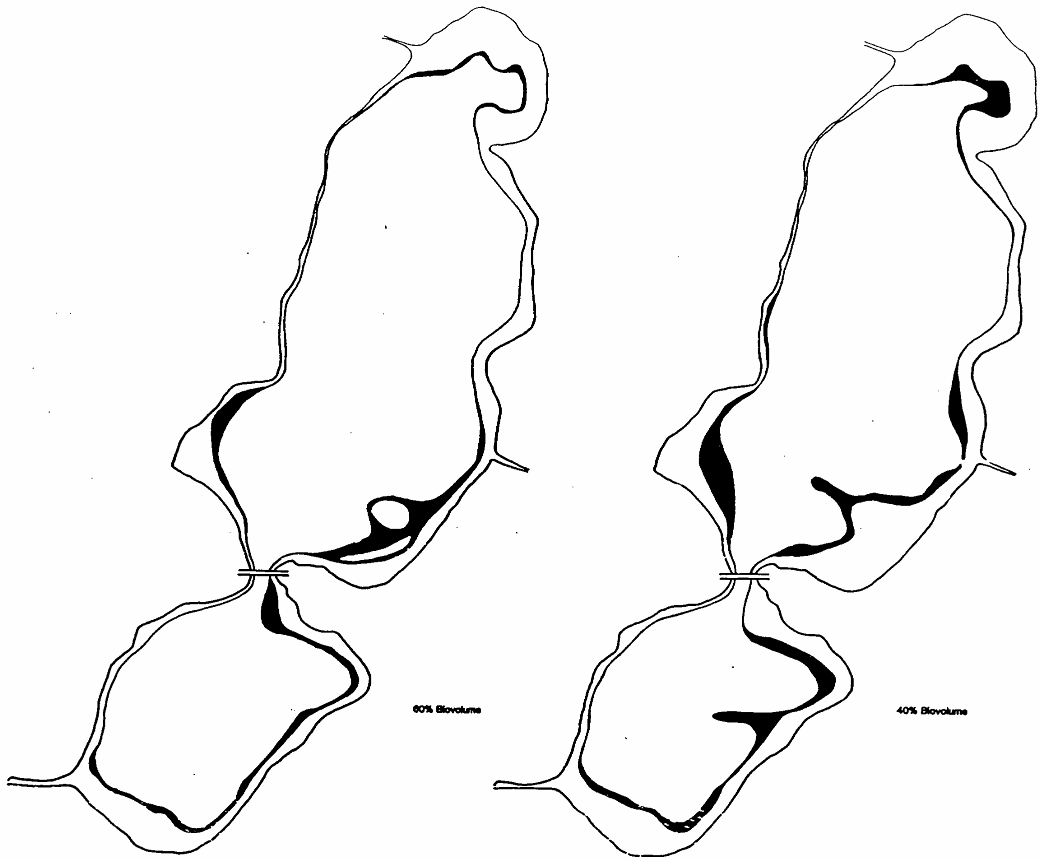
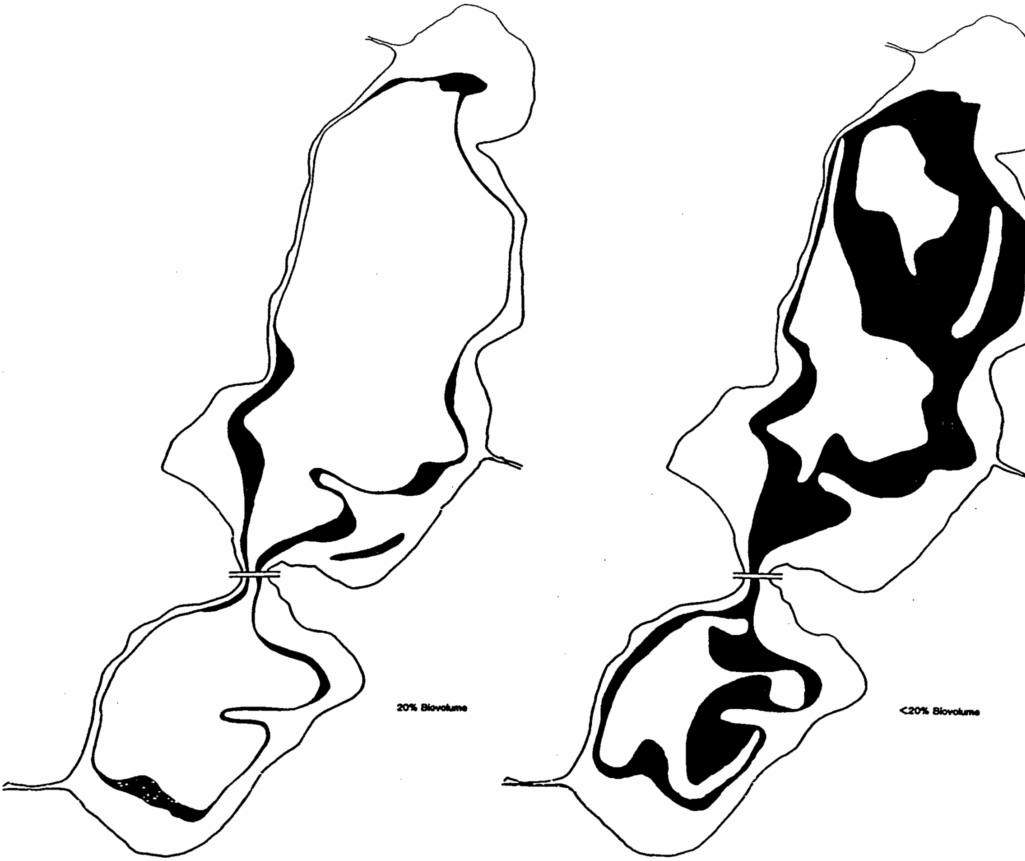


Figure 23 (Continued)



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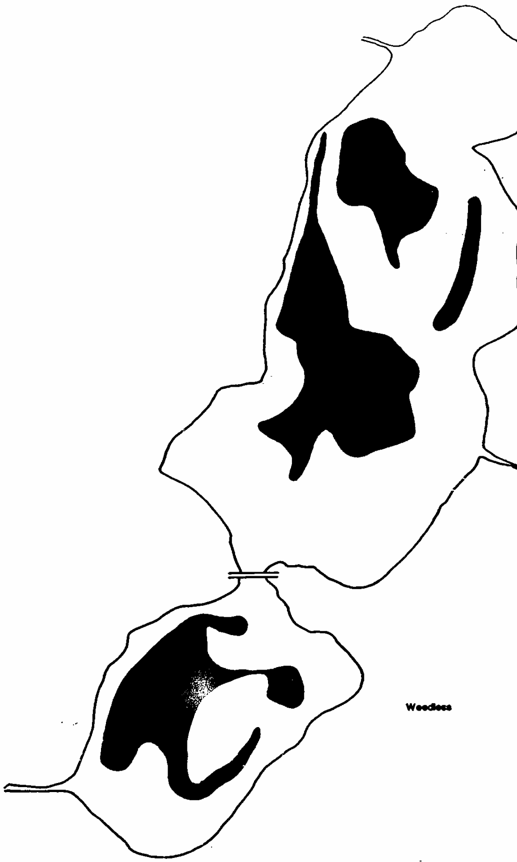


Figure 23. (Continued)

than the 100% category and in slightly deeper water. This zone reached its maximum aerial extent in the northeastern corner of the north basin. In both basins, plant growth appeared to be more extensive on the eastern rather than the western shores. The 60%, 40% and 20% biovolume zones were greatest in the southern portion of the north basin and along the eastern shore of the south basin, while the less than 20% and weedless zones were restricted to the deepest portions of both basins.

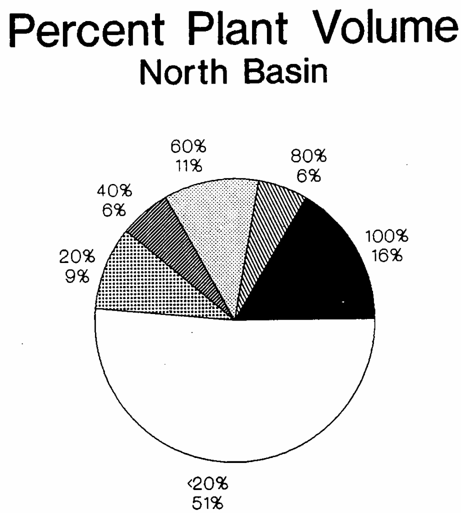
Aquatic plants filled 80-100% of the water column under 16.6% and 20.6% of the surface area of the north and south basins, respectively (Figure 24). Using 80% biovolume as the cutoff defining serious management problems, 17.7% of the entire surface area of Nyona Lake is plagued by excessive macrophytes (Figure 25). In marked contrast, 63.7% of the area of the north basin and 58.3% of the south basin are characterized by plant biovolumes less than 20%, thus posing no management problems.

Macrophyte problems in the north basin appear to be restricted to water less than 5 feet deep (Table 10). Approximately 47% of the area of the 0-5 foot depth interval is completely choked with weeds, while an additional 14.6% of the area has a biovolume of greater than 80%. In marked contrast, most of the 5-10 foot depth interval displayed a plant biovolume of only 1-20%.

A similar pattern was displayed by the south basin (Table 11). Weed problems also were generally restricted to water depths less than 5 feet with approximately 62% of the area of the 0-5 foot depth contour completely choked with aquatic macrophytes. The results from both basins clearly demonstrate that aquatic weeds display pronounced light limitation below five feet water depth and suggest that only those areas less than this critical depth are in need of plant management.

Actual plant heights for both basins of Nyona Lake are presented in Figure 26. For clarity, the distribution of individual 2-foot plant height increments have been presented in Figure 27. Plant heights 6-8 feet tall were recorded only in two extremely small areas of the south basin and are considered to have little bearing on the overall distribution of plant growth in the lake. Similarly, the south basin also had the greatest extent of plant growth 4-6 feet tall with maximum development along the eastern shore in water 5-10 feet deep.

Plant growth 2-4 feet tall reached maximum in the northern and southeastern sections of the north basin and in water 5-10 feet deep in the south basin. Plants less than 2 feet tall were found along the shore of both basins as well as in water greater than 10 feet deep. A majority of the



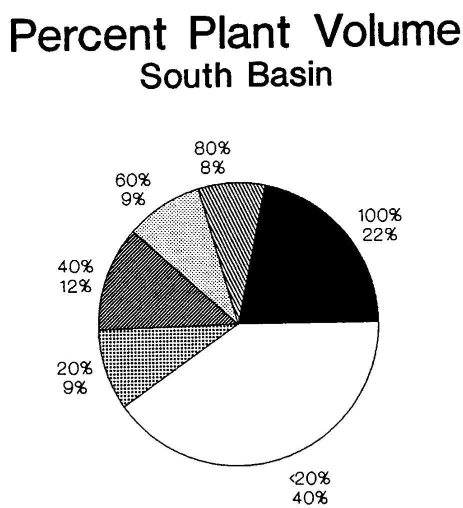


Figure 24. The Distribution of Plant Biovolume in the North and South Basins of Nyona Lake Expressed as a Percent of Water Column Infestation.

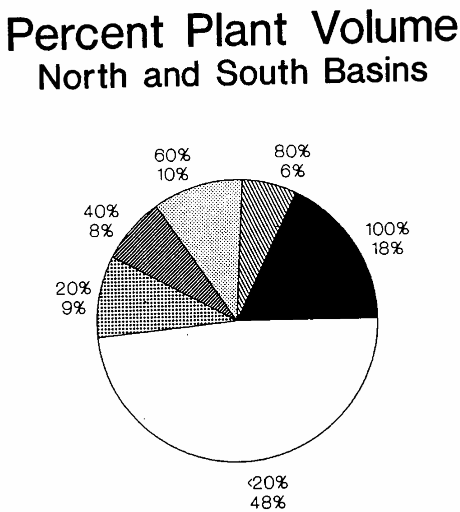


Figure 25. The Distribution of Plant Biovolume in Nyona Lake Expressed as a Percent of Water Column Infestation.

Table 10. Macrophyte biovolume (20% increments) expressed as percent aerial coverage for both individual five foot contour intervals and the entire area of the North Basin of Nyona Lake.

Interval	Biovolume %	Area Acres	% Area Contour Interval	% Basin Area
0-5 feet	100	9.18	46.8	12.3
	80-99	2.87	14.6	3.8
	60-80	4.08	20.8	5.4
	40-60	0.72	3.7	1.0
	20-40	0.46	2.3	0.6
	1-20	2.06	10.5	2.8
	0	0.23	1.2	0.3
5-10 feet	100			
	80-99	0.37	2.2	0.5
	60-80	2.05	12.1	2.7
	40-60	2.10	12.4	2.8
	20-40	3.69	21.9	4.9
	1-20	7.30	43.3	9.7
	0	1.37	8.1	1.8
10-15 feet	100			
	80-99			
	60-80			
	40-60	0.51	2.4	0.7
	20-40	1.11	5.1	1.5
	1-20	13.35	61.7	17.8
	0	6.67	30.9	8.9
15-20 feet	100			
	80-99			
	60-80			
	40-60			
	20-40	0.02	0.2	0.1
	1-20	5.35	44.9	7.1
	0	6.54	54.9	8.7
20-25 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20	0.54	18.1	0.7
	0	2.46	81.9	3.3
>25 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20	0.20	10.4	0.3
	0	1.72	89.6	2.3

Table 11. Macrophyte biovolume (20% increments) expressed as percent aerial coverage for both individual five foot contour intervals and the entire area of the South Basin of Nyona Lake.

Interval	Biovolume %	Area Acres	% Area Contour Interval	% Basin Area
0-5 feet	100	4.38	62.5	14.6
	80-99	1.24	17.7	4.1
	60-80	0.80	11.5	2.7
	40-60			
	20-40			
	1-20	0.58	8.3	1.9
	0			
5-10 feet	100	0.16	1.8	0.5
	80-99	0.37	4.2	1.2
	60-80	1.04	11.9	3.5
	40-60	2.29	26.3	7.7
	20-40	1.57	18.0	5.3
	1-20	2.18	24.9	7.3
	0	1.12	12.8	3.7
10-15 feet	100			
	80-99			
	60-80	0.01	0.2	0.1
	40-60	0.23	3.8	0.8
	20-40	0.36	5.9	1.2
	1-20	3.31	54.1	11.0
	0	2.20	36.0	7.4
15-20 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20	2.16	44.8	7.2
	0	2.67	55.2	8.9
20-25 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20	0.19	7.9	0.6
	0	2.24	92.1	7.5
>25 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20			
	0	0.82	100.0	2.8

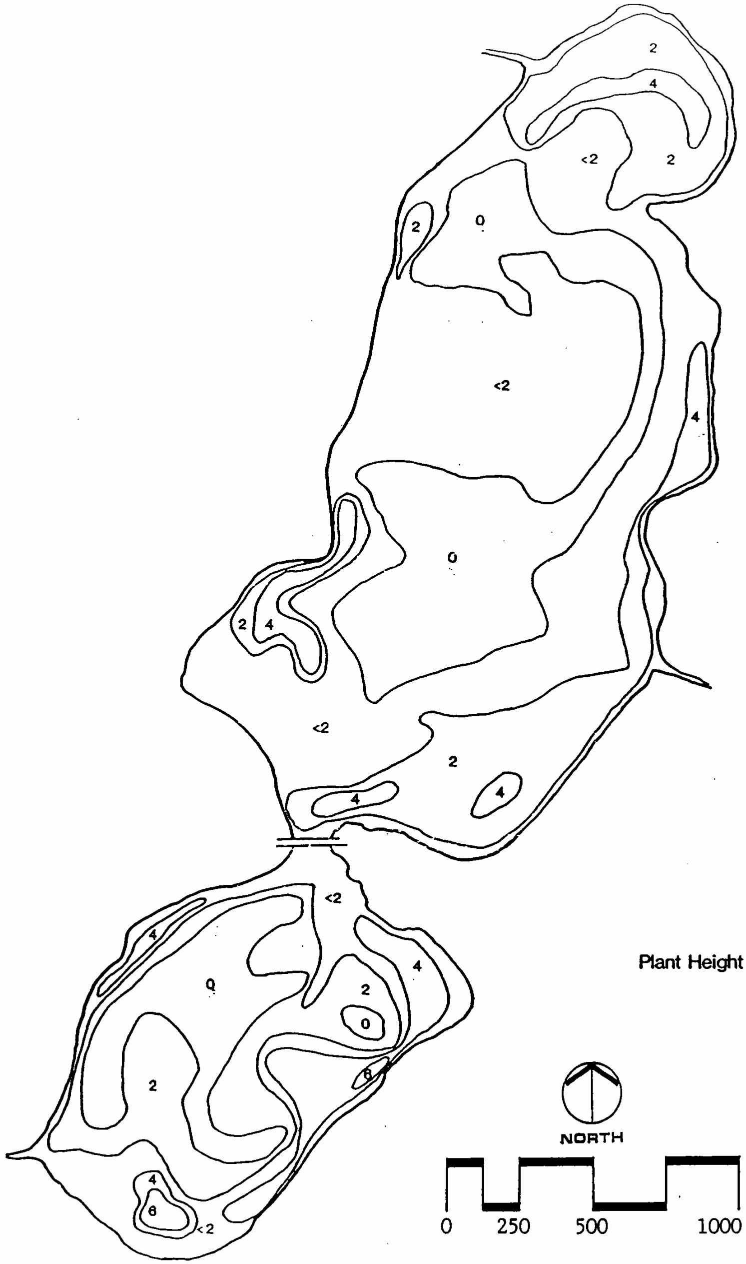


Figure 26. The Height of Aquatic Weeds in Nyona Lake in 1989.

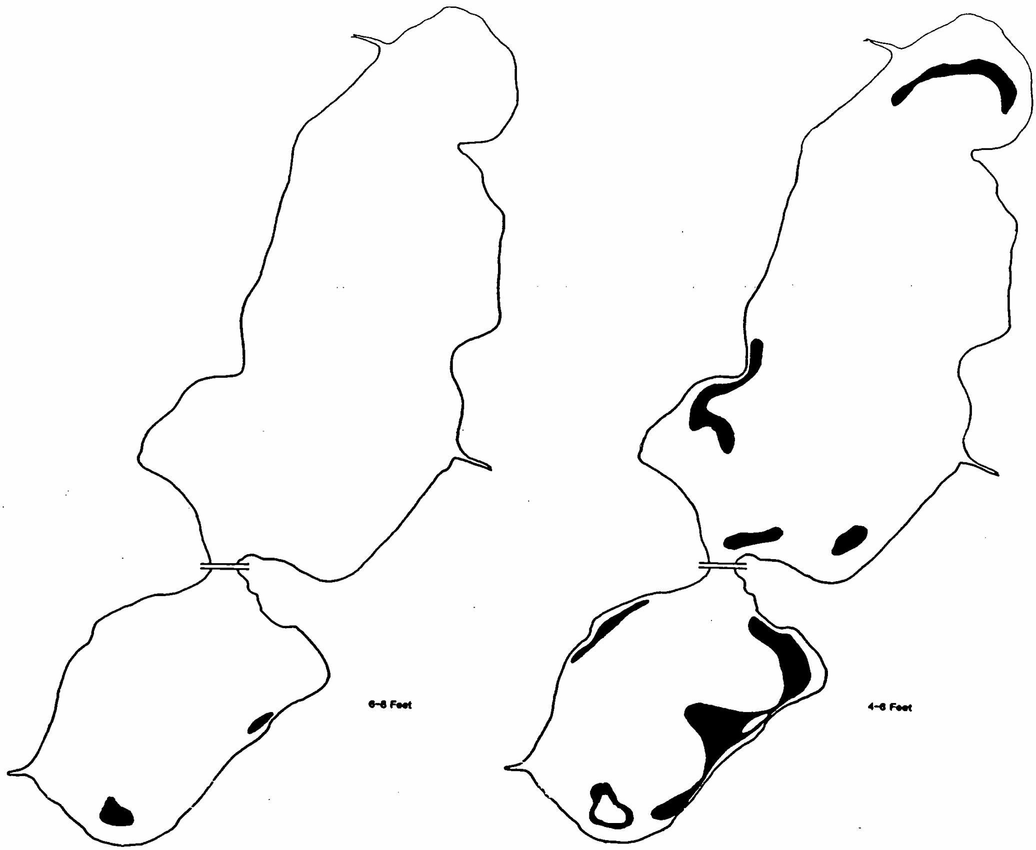


Figure 27. The Distribution of Aquatic Plant Height in Nyona Lake by 2 Foot Height Increments.

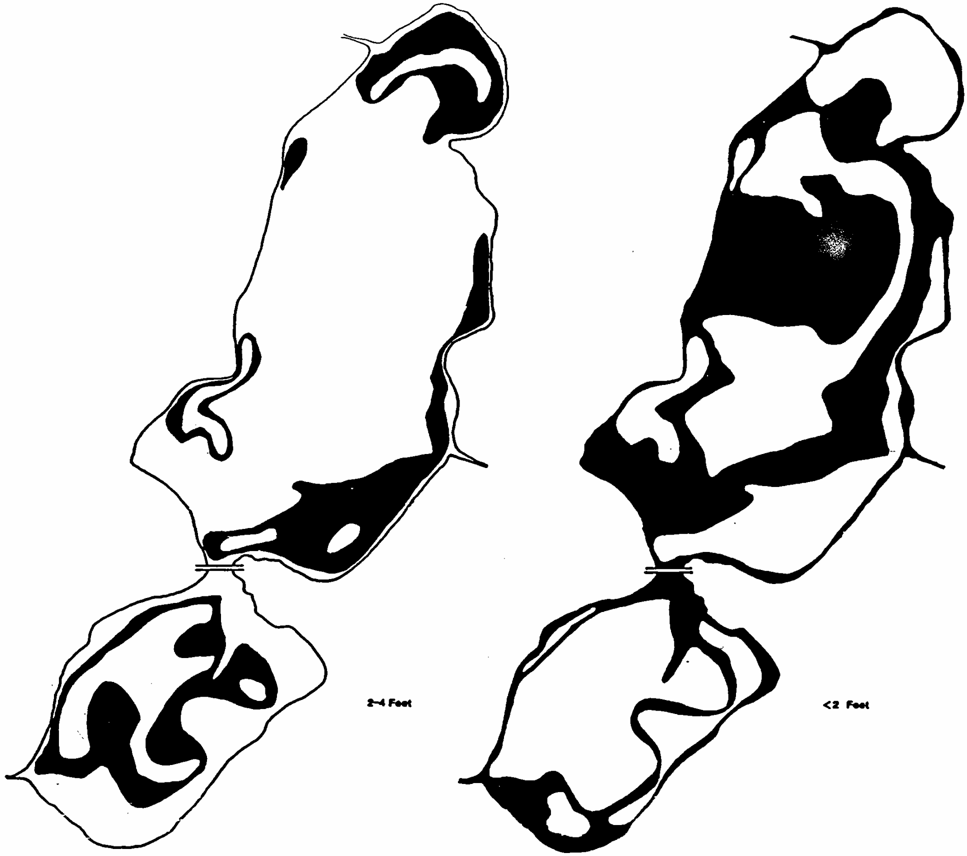


Figure 27. (Continued)

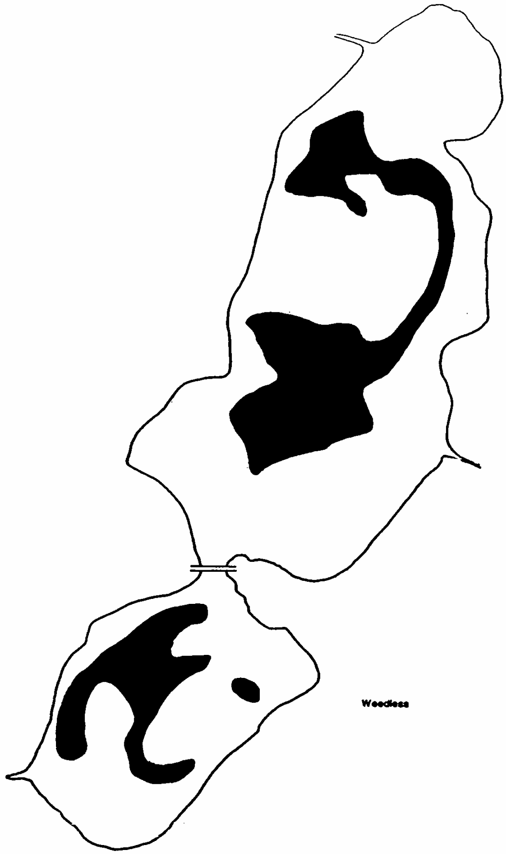


Figure 27. (Continued)

weed problems along the shores of both basins are associated with such short vegetation that completely fills the water column of nearshore areas. As noted earlier, the deepest sections of both basins are completely weedless due to pronounced light limitation for plant growth.

In addition to looking at the distribution of plant biomass in Nyona Lake, a qualitative survey was made to determine the distribution of the major plant species in the system. Sketches of the most important macrophyte species in Nyona Lake are presented in Figure 28, and their distribution in both the north and south basins are given in Figures 29 and 30, respectively. The exotic species, Myriophyllum spicatum (Eurasian watermilfoil), was the dominant submergent plant in the north basin. This plant is the principal contributor to total plant biomass and should be the target of any aquatic management program. It is interesting to note that Eurasian watermilfoil was not reported from Nyona Lake prior to 1973 (Table 6), and that a native ecological equivalent, Ceratophyllum (coontail) was one of the dominant submergent plants. By 1989, however, coontail was extremely restricted in its distribution and obviously being replaced by watermilfoil in recent years. Nearshore areas of the north basin, especially along the relatively undisturbed eastern shore, were characterized by patches of eelgrass (Vallisneria) and two species of pondweed (Potomogeton). Water lilies (Nuphar) were restricted to undeveloped sections of the eastern shore and the inlet from the Martin-Whitmore Ditch. The Nuphar at the latter location is likely serving a beneficial purpose in trapping some of the nutrients and silt delivered by this ditch. It is interesting to note that in general watermilfoil reaches its greatest extent in the north basin in areas of highest number of houses and is relatively less pronounced along the undeveloped sections of the eastern shore.

As noted for the north basin, the exotic species Myriophyllum spicatum (Eurasian watermilfoil) is the dominant plant found in the south basin (Figure 30). With the exception of the northwest corner of the basin and small patches along the eastern shore, few additional plant species were found. Watermilfoil is clearly the problem plant species in both the north and south basins of Nyona Lake with the most serious infestation occuring in water <5 feet deep.

Fish

The Raytheon fathometer data recorded from the 29 cross lake transects were also used to provide a qualitative assessment of the fish community of Nyona Lake. Echos of fish in the water column appear on all fathometer

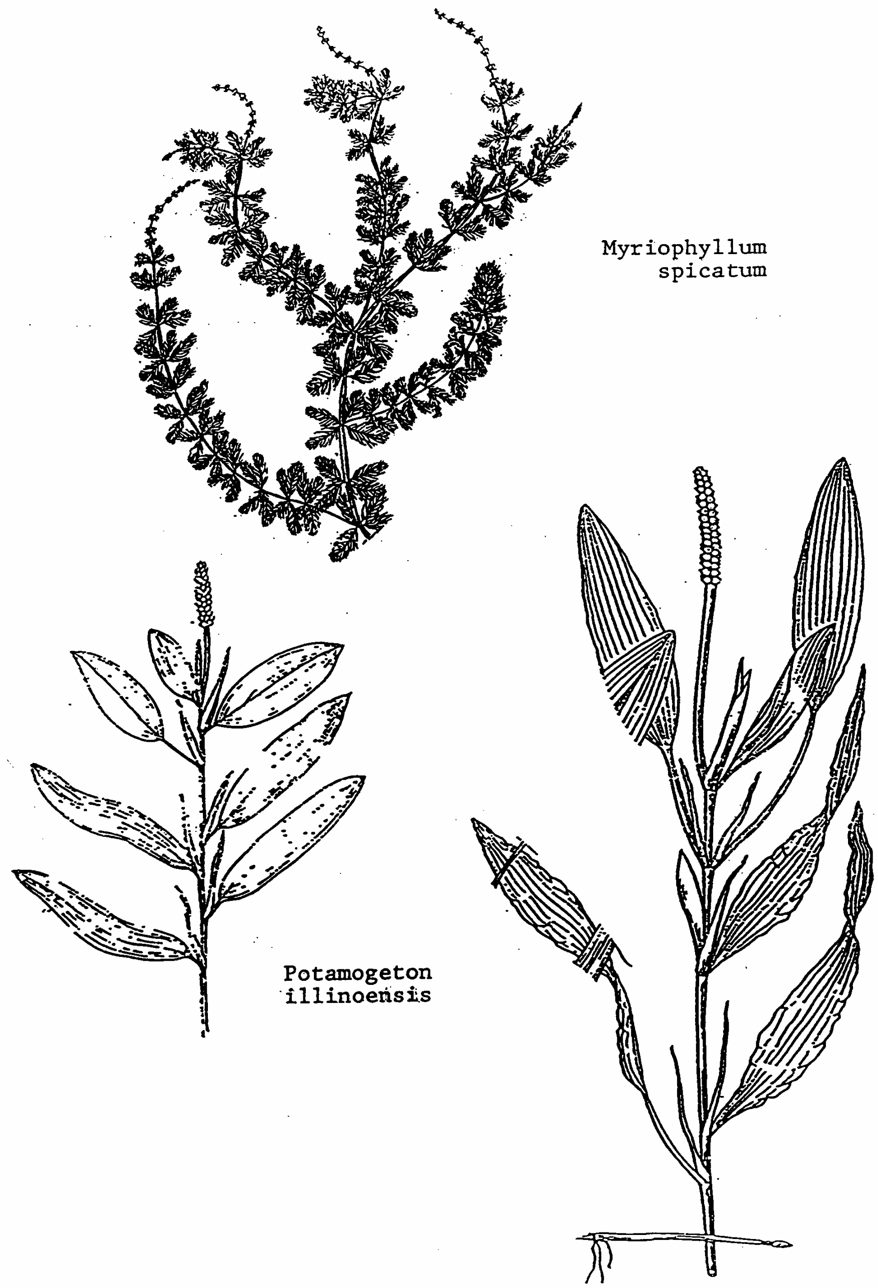
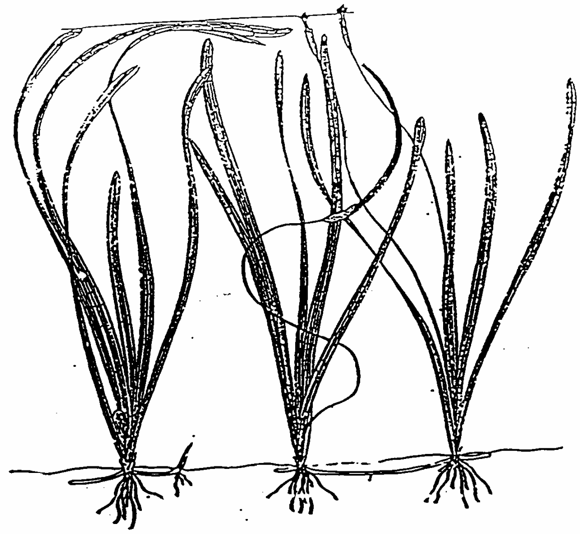
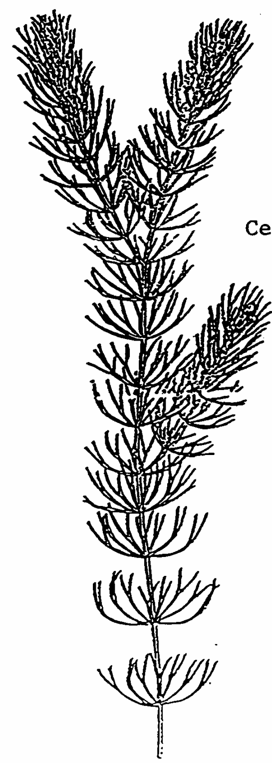


Figure 28. Common Plant Taxa Found in Nyona Lake during 1989. Drawings adapted from Fassett (1940) and Correll and Correll (1972).

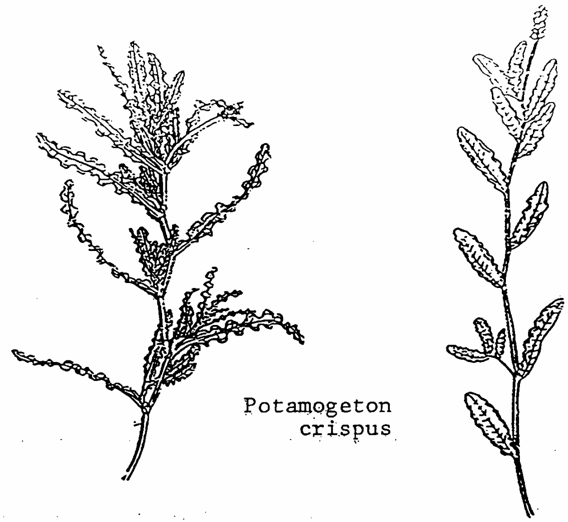


Vallisneria

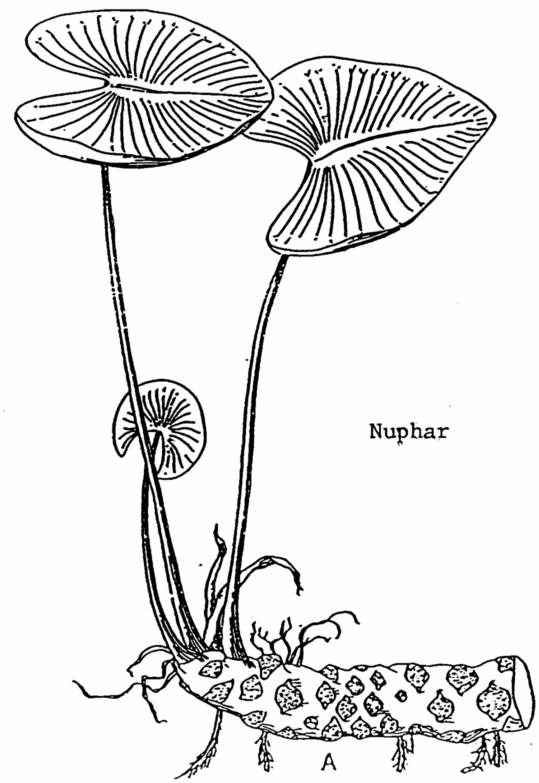


Ceratophyllum

Figure 28. (Continued)



Potamogeton
crispus



Nuphar

Figure 28. (Continued)

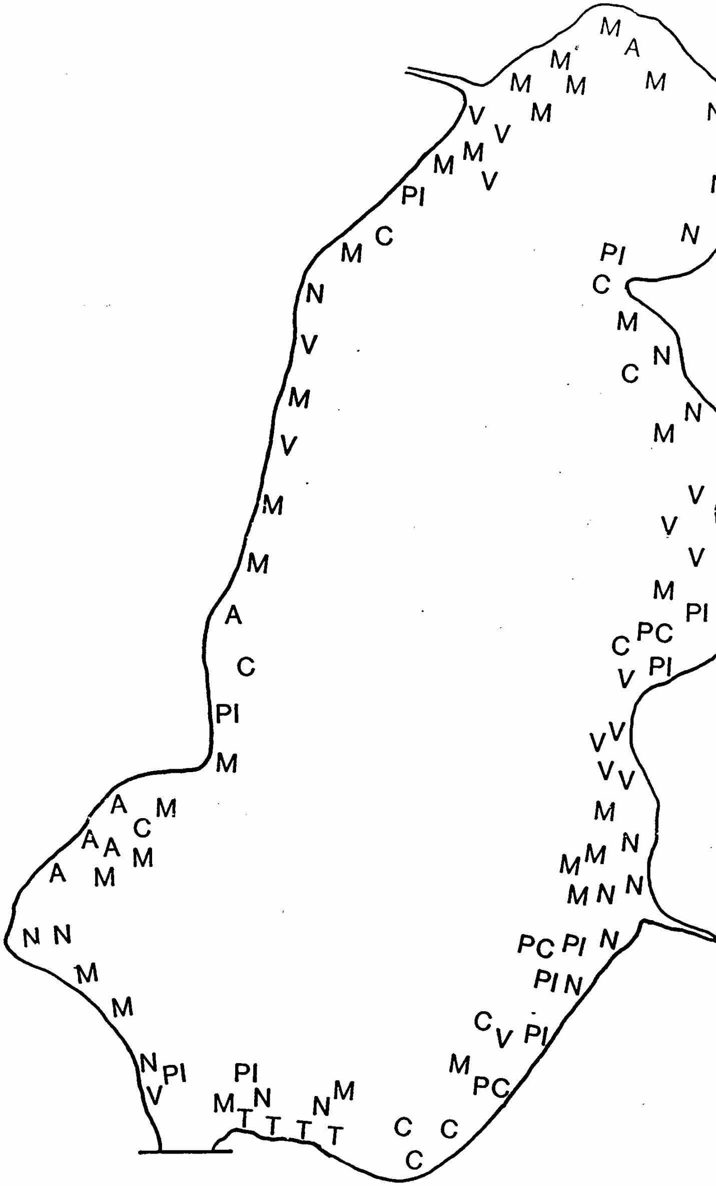


Figure 29. Distribution of Major Plant Taxa in the North Basin of Nyona Lake in 1989. Plants were: Algae (A), Ceratophyllum (C), Myriophyllum (M), Nuphar (N), Potamogeton crispus (PC), Potamogeton illinoensis (PI), Typha (T), and Vallisneria (V).

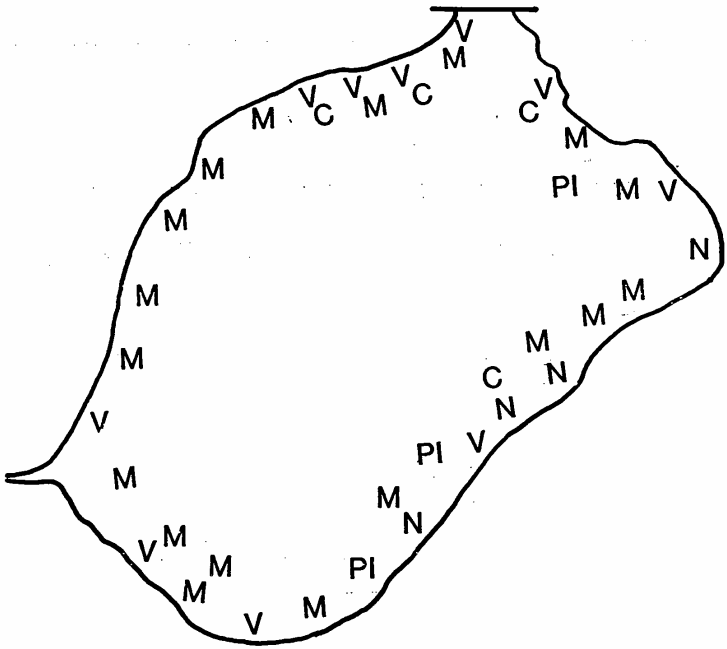


Figure 30. Distribution of Major Plant Taxa in the South Basin of Nyona Lake in 1989. Plants were: Ceratophyllum (C), Myriophyllum (M), Nuphar (N), Potamogeton illinoensis (PI), and Vallisneria (V).

recordings, and these were used to assess total fish abundance and the depth distribution of the population for each basin.

For interbasin comparison, fish data were presented on the basis of number individuals per 1000 feet of fathometer transect (Figure 31). The tracings suggest that fish in the north basin (45/1000 feet transect) are more abundant than in the south basin (34/1000 feet transect). Given the highly qualitative nature of the database, however, it is likely that such interbasins are not significantly different. Any basin differences may be attributable to the fact that the north basin has a much more developed vegetated littoral fringe that could afford better protection to young fish.

Depth distributions of fish during July 1989 have been presented for the north and south basins (Figure 32) as well as the whole Nyona Lake system (Figure 33). The greatest density of fish in both the north (57% total abundance) and south (58% total abundance) basins was at a depth of 3-5 feet. Fish avoided shallower water, the area of highest water temperatures, as well as depths greater than 11 feet, the zone of reduced oxygen. It is clear that fish during midsummer stay as deep as possible to avoid warm water while still having sufficient oxygen to avoid stress. If trophic state can be reduced, fish will expand their depth distribution as oxygen concentrations in the deeper portions of the water column increase. It must also be noted, however, that oxygen is only one of many factors controlling fish distributions. The dense weeds at depths less than 10 feet may exclude many fish. Effective reduction in plant biomass will likely open new habitats for both feeding and reproduction.

Bathymetric Map and Lake Infilling

The Indiana DNR in association with the United States Geological Survey published a bathymetric map of Nyona Lake based on a survey of 1954 (Figure 34). Depth contours were constructed at five foot intervals for both basins of the lake. The current study constructed an updated bathymetric map for 1989 based on fathometer recordings obtained from 29 lake transects (Figure 35). Following convention established by the 1954 map, five foot contours were constructed for the 1989 map.

It is obvious that the depth configuration has changed markedly in the past 35 years. A comparison of the depth distributions of the north and south basins for 1954 and 1989 are provided in Figure 36. The north basin historically has had approximately three times the area of 0-5 feet deep water as the south basin. With the exception of the two deepest contours (25-30, 30-32 feet) the area of the north

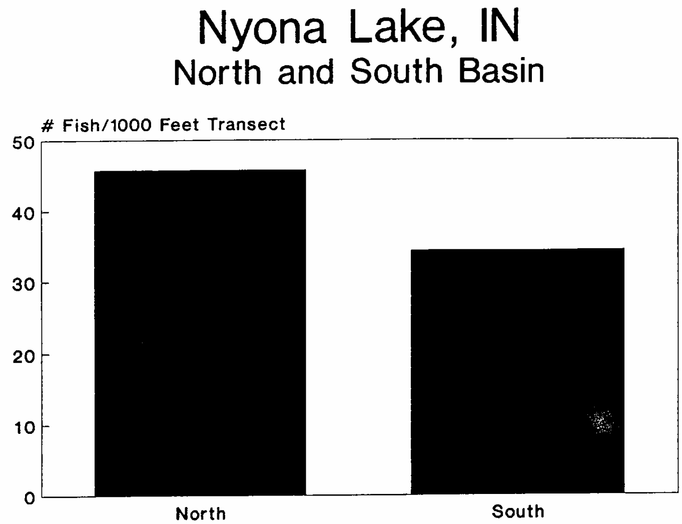
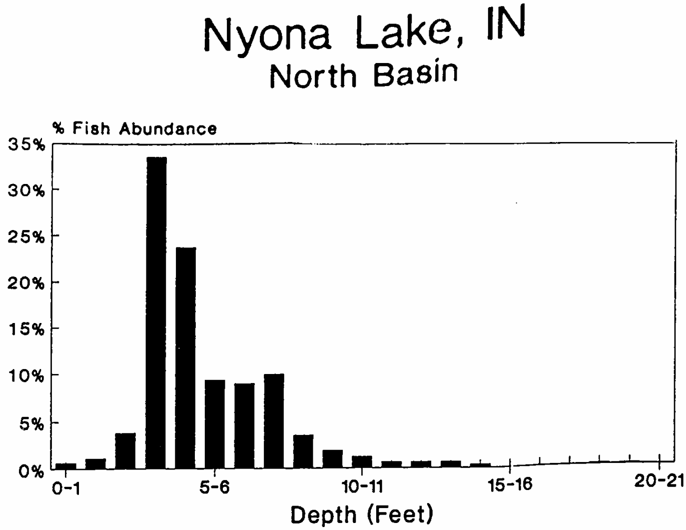


Figure 31. Semi-Quantitative Estimate of Fish in Nyona Lake in July 1989 Expressed as Number of Individuals Per 1000 Feet of Fathometer Transect.



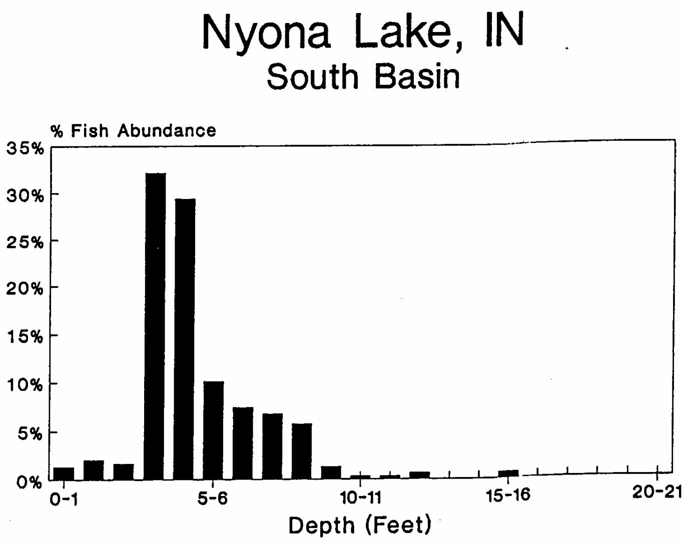


Figure 32. Depth Distribution of the Fish Community in the North and South Basins of Nyona Lake in July 1989 as Estimated from Fathometer Transect.

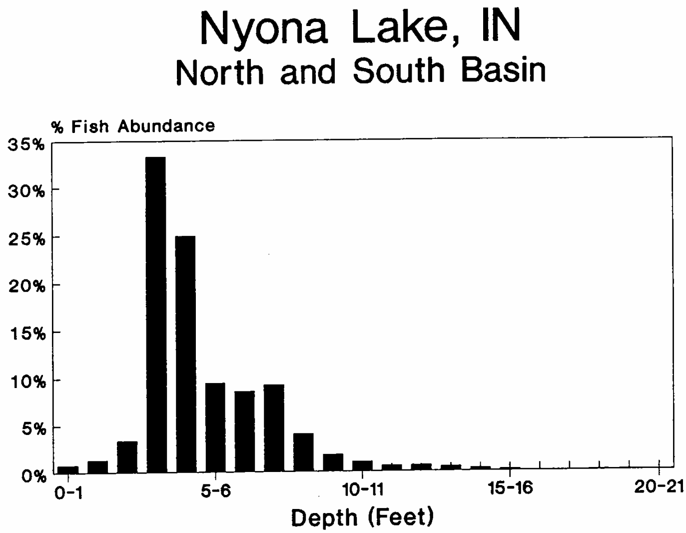


Figure 33. Depth Distribution of the Fish Community in Nyona Lake in July 1989 as Estimated from Fathometer Transects.

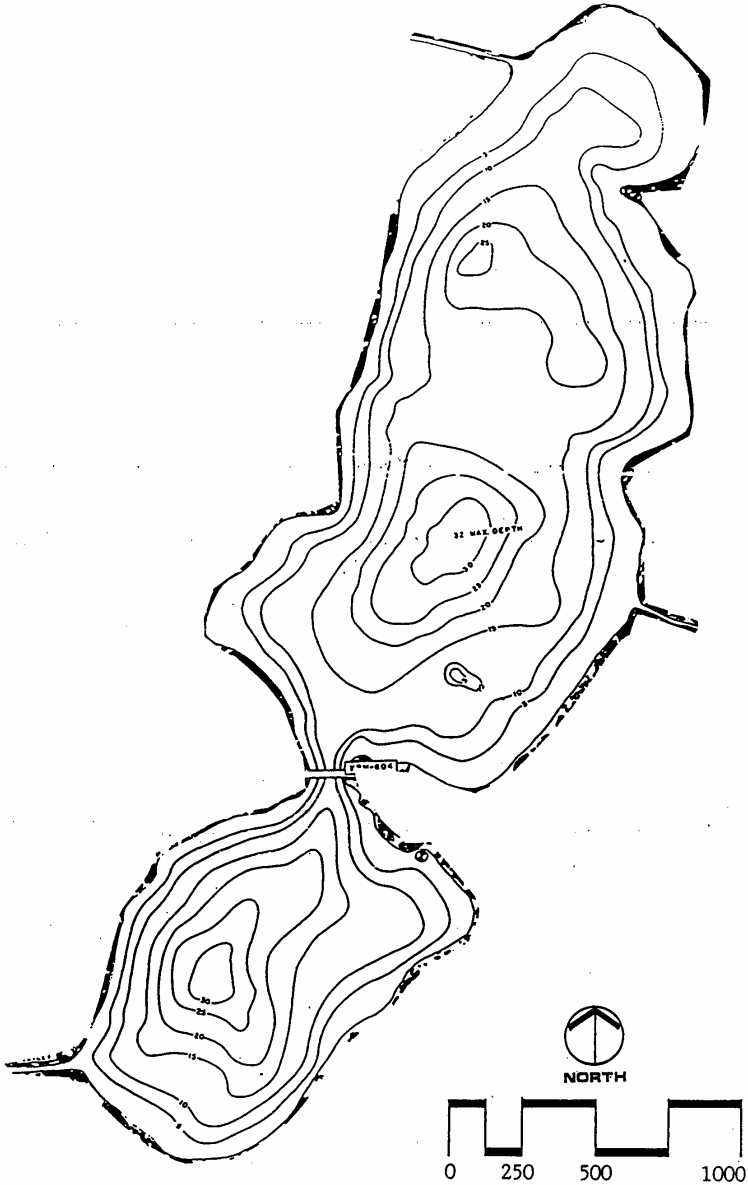


Figure 34. Bathymetric Map of Nyona Lake from 1954.

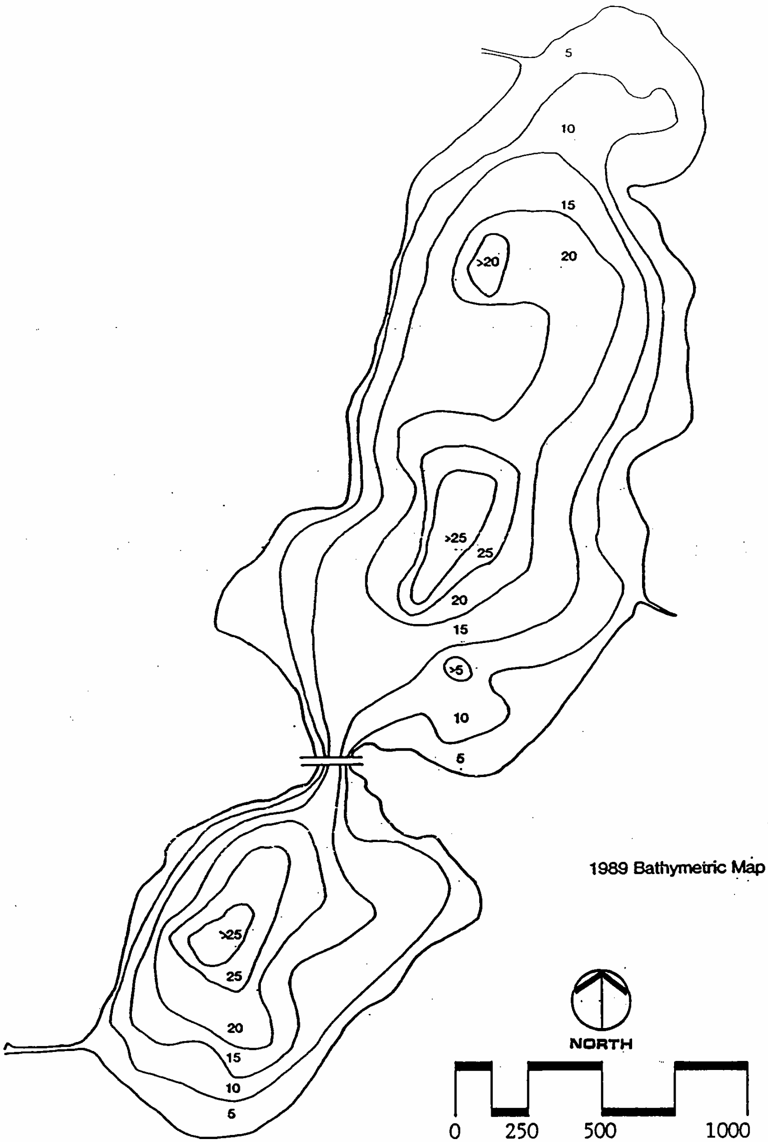
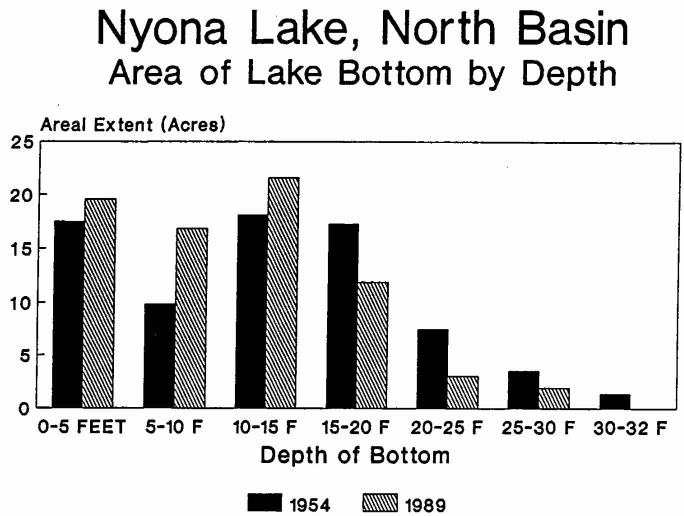


Figure 35. Bathymetric Map of Nyona Lake from 1989.



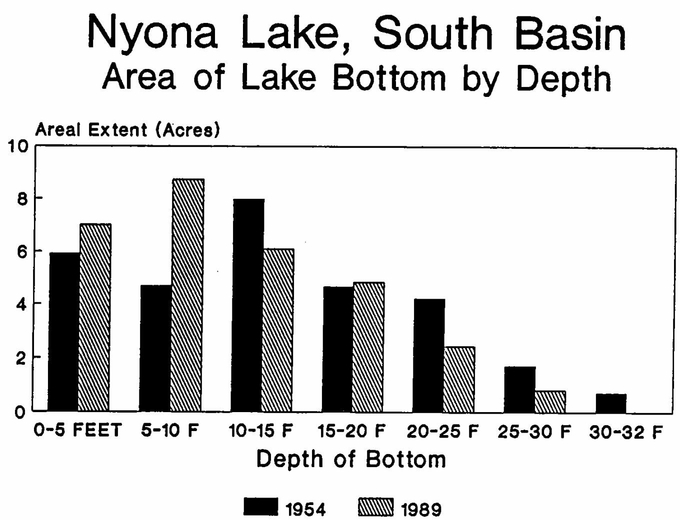


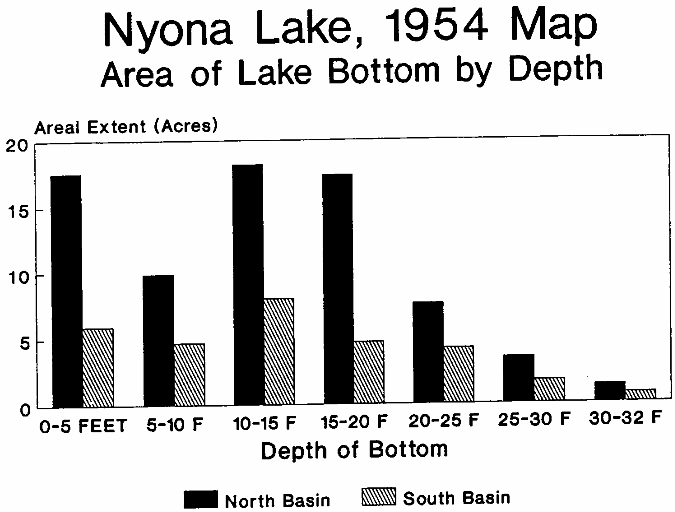
Figure 36. Comparison of the Aerial Extent of Individual Depth Contours Between the North and South Basin of Nyona Lake for 1954 and 1989.

basin is at least double that of the south basin for all contour intervals. The most pronounced differences between the 1954 and 1989 maps was for the 10-15 and 15-20 foot intervals. While the north basin had greater area for the former interval in 1954, the rank order was reversed by 1989. In addition, the magnitude of the difference between the two basins for the latter contour was markedly reduced by 1989.

Each of the three shallowest depth contours (0-5, 5-10, 10-15 feet) in the north basin increased in aerial extent between 1954 and 1989 (Figure 37) with the greatest increase being displayed by the 5-10 foot contour (42%). In marked contrast, all contours greater than 15 feet decreased in extent during the 35 year period. The shallow water zone of the south basin also increased in its extent between 1954 and 1989, but unlike the north basin, the shoaling was restricted to water depths less than 10 feet deep. As noted for the north basin, however, the greatest percentage aerial increase (53%) was recorded for the 5-10 foot contour. With the exception of the 15-20 foot contour, all sections of the south basin greater than 10 feet deep displayed pronounced infilling during the 35 year period.

Infilling was not uniform throughout the north basin but was most pronounced in the vicinity of Fouts Ditch and Martin-Whitmore Ditch inlets and was least pronounced along the western shore and the undeveloped sections of the eastern shore. In contrast, infilling in the south basin was more uniform throughout.

It is clear that basin sedimentation in the north basin is strongly controlled by stream input of watershed erosion products. This has resulted in a major volume loss for all depth contours during the past 35 years. While it is likely that watershed sediment entering the north basin also contributed to infilling within the south basin, shallow water shoaling in the latter basin is likely the result of within lake erosion and redeposition. Two factors are likely responsible for shallow water sediment erosion and associated redeposition in deeper water. The grasses, cattails and other emergent vegetation growing in nearshore areas act to reduce the erosion action of waves. Our research at Lakes-of-the-Four-Seasons (Crisman and Eviston 1989) and Koontz Lake (Eviston and Crisman 1988) has clearly demonstrated that removal of such vegetation by homeowners wanting easier access to their docks enhances the erosion action by waves and thereby promotes shoaling of offshore areas. The second factor for promoting shallow water erosion is waves generated by speed boats. Our research at Lake Maxinkuckee (Crisman et al. 1990) clearly addressed this point. Waves are normally only produced in lakes during storm events. Intense boating activity produces waves that approximate those generated during storms. Such waves



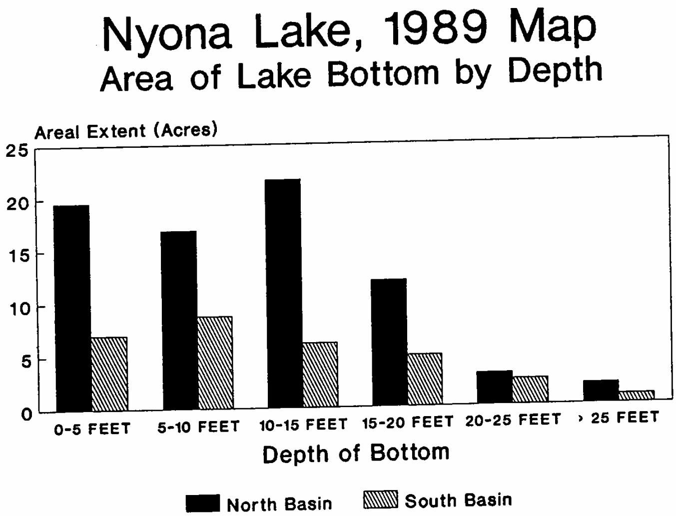


Figure 37. Comparison of the Aerial Extent of Individual Depth Contours Within the North and South Basins of Nyona Lake for 1954 versus 1989.

increase nearshore erosion, stir nutrients from bottom waters and promote algal growth. It is apparent that boating has contributed significantly to shallow water shoaling in both the north and south basins, but separation of its contribution to total sedimentation in the north basin is complicated by the second major sedimentation factor, stream input of eroded sediment from the watershed.

Sediment Studies

Sediment Contaminants

A piston coring device equipped with a clear plexiglass tube was used to collect a one-meter core from the deepest section of the north basin of Nyona Lake. This technique permitted examination of the core to insure that the sediment-water interface was not disturbed during the coring operation. The core was extruded in 10 cm sections and placed in labelled plastic bags. All core material was kept cool at 4^{o} C until analyzed. Prior to analysis, the 0-10 cm interval was thoroughly mixed and extracted for metal and organic contaminant analyses. This upper most interval provided sufficient material for our investigation.

The metals and organics data are presented in Table 12. A total of 20 metals were analyzed with the highest concentrations being exhibited by calcium, iron, aluminum, magnesium, and manganese. All metal values were considered within the range expected for the glaciated portion of Indiana. In addition, 24 possible organic contaminants were analyzed. As with the metals, concentrations were not considered to pose any environmental threat. Given that none of the 44 analyzed parameters were considered to exceed permissible levels, it is most probable that the sediments throughout the remainder of Nyona Lake are free from serious chemical contamination as well.

Sediment Core Profiles

Sediment cores were collected at the deepest location of both the north and south basins of Nyona Lake (Figure 38) by means of the same piston coring device described in the previous section of this report. As always, the plexiglass tubing permitted inspection of the core to insure that the sediment-water interface was left undisturbed during the coring operation. Only those cores which we felt absolutely met this requirement were saved for analysis. The total core lengths collected from the north and south basins were 107 cm and 112 cm, respectively.

Both cores were extruded within two hours of

Table 12. Concentrations of Metals and Organic Chemical Contaminants in Surface Sediments of the North Basin of Nyona Lake.

METALS	ug/g dry wgt	ORGANICS	ug/g dry wgt
% Solids	20.8	2,4,5-T	<0.7
Ag	<5	2,4,5-TP (Silvex)	<0.7
Al	23000	2,4-D	<0.7
Ba	241	2,4-DB	<0.7
Be	1	B-BHC	<0.01
B	22	D-BHC	<0.01
Cd	3	Methoxychlor	<0.2
Ca	136000	Toxaphene	<0.2
Cr	27	4,4´-DDD	<0.02
Cu	61	4,4´-DDE	<0.02
Fe	23300	4,4´-DDT	<0.02
Pb	31	A-BHC	<0.01
Mg	7800	Aldrin	<0.01
Mn	753	Chlordane	<0.02
Mo	6	Dieldrin	<0.01
Na	193	Endosulfan I	<0.02
Ni	23	Endosulfan II	<0.01
Sr	123	Endosulfan sulfate	<0.05
Ti	298	Endrin aldehyde	<0.02
V	68	Endrin	<0.01
Zn	115	G-BHC (Lindane)	<0.01
		Heptachlor epoxide	<0.05
		Heptachlor	<0.01
		PCB´s	<0.05

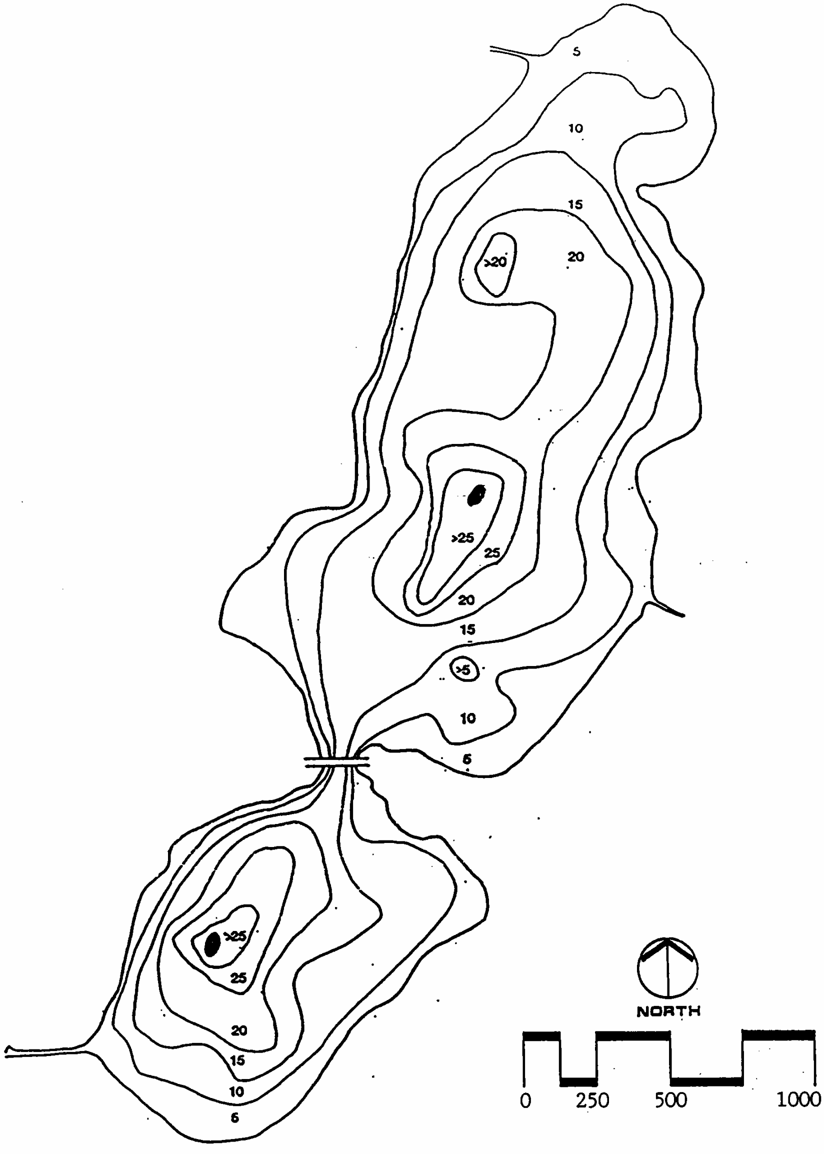


Figure 38. Sites of Sediment Core Collection in Nyona Lake During 1989.

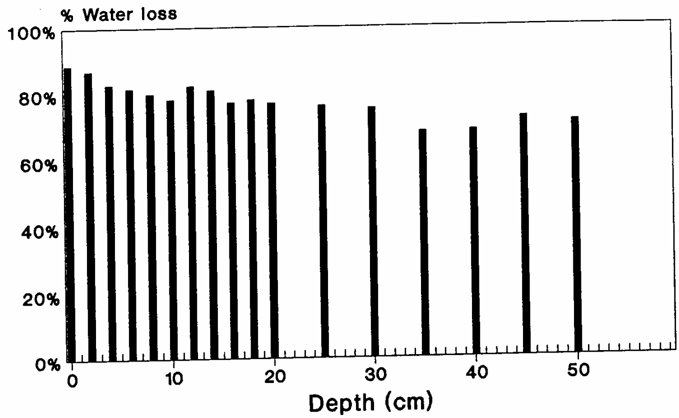
collection. Each core was sectioned at 1 cm intervals with each sample being placed in a plastic bag for storage. All samples were then kept at 4^{o} C until analyzed. In addition to wet weight for select core levels, organic content was calculated as the difference in weight between the wet weight and that after drying at 100^{o} C for 24 hrs. Inorganic content was calculated from the weight difference of the sample dried at 100^{o} C for 24 hrs and ashed at 500^{o} C for one hour. Phosphorus was determined by the standard ascorbic acid colorimetric method using filtrate collected from an HCl digestion of the sediment sample.

Water content of north basin core increased progressively from 60% at a depth of 110 meters to 88% in the surficial sediments (Figure 39). The core from the south basin was less compact throughout its length and consistently displayed water content in excess of 75% throughout (Figure 39). The "soupiness" of the surface sediments in both north and south basin cores, however, was comparable.

Profiles of sediment inorganic content for both the north and south basin cores are presented in Figure 40. While the south basin core contained less than 20% inorganic matter throughout its length with a slight decline noted in the most recently deposited sediments, the north basin core percentage of inorganic matter displayed a progressive increase from approximately 12% at 110 cm to 17% in the most recently deposited sediments. The initially higher percentage of inorganic sediments in the south basin is likely a reflection of the fact that the basin is smaller and wave action is likely to deposit inorganic sediments from the shallows into the rather restricted deep water section. We feel, however, that increased inorganic sediment deposition in the top 15 cm of the north basin core reflects increase input of watershed erosional material via streams.

Sediment organic content profiles are the mirror image of inorganic profiles in both the north and south basins (Figure 41). Organic content in the south basin core decreased from 18% at 110 cm to 15% at 70 cm then increased slightly to 17% where it remained until 20 cm. The percentage of the upper 20 cm dropped slightly to 15-16%. The lowermost (107 cm) organic percentage in the north basin core was slightly lower than that of the south basin at a comparable depth (13 vs 18%) but values increased progressively to the present to peak at 16%. It is normal for eutrophic Indiana lakes to deposit in excess of one meter of sediment in one hundred years (Crisman 1987). The slight variability in the percentage of inorganic and organic matter in both cores suggests that the relative contribution of each has changed little in the past 100 years. Such an interpretation, however, does not imply that the annual sedimentation of these parameters has remained

Nyona Lake, IN
North Basin



Nyona Lake, IN
South Basin

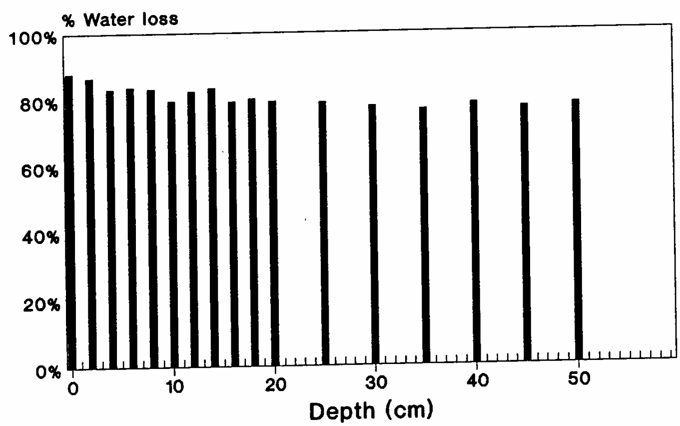
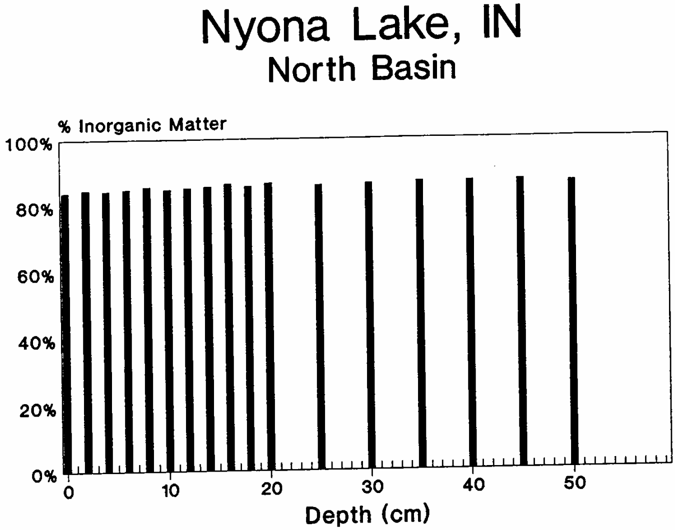


Figure 39. Profiles of Percent Water in Sediment Cores from the North and South Basins of Nyona Lake.



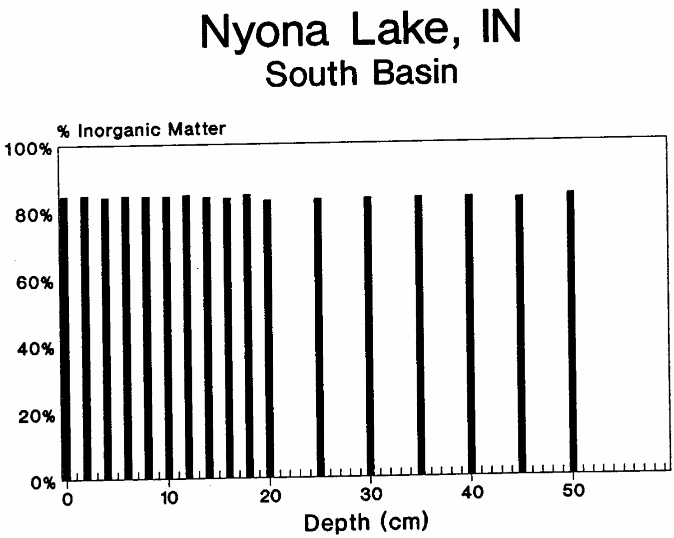
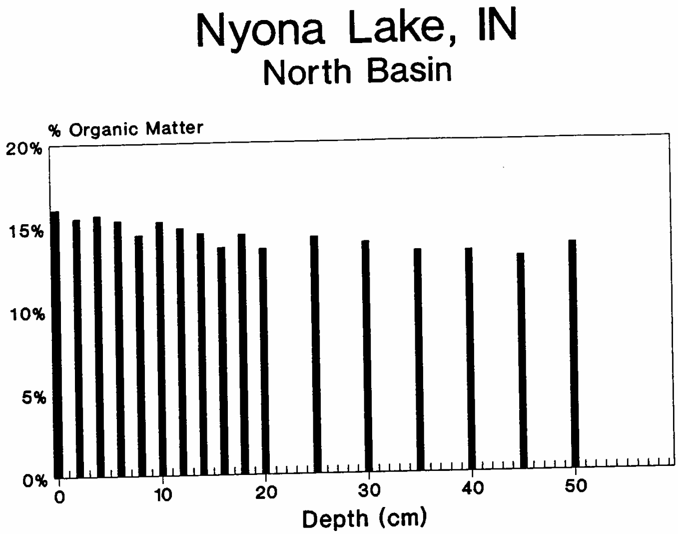


Figure 40. Profiles of Percent Inorganic Matter in Sediment Cores From the North and South Basins of Nyona Lake.



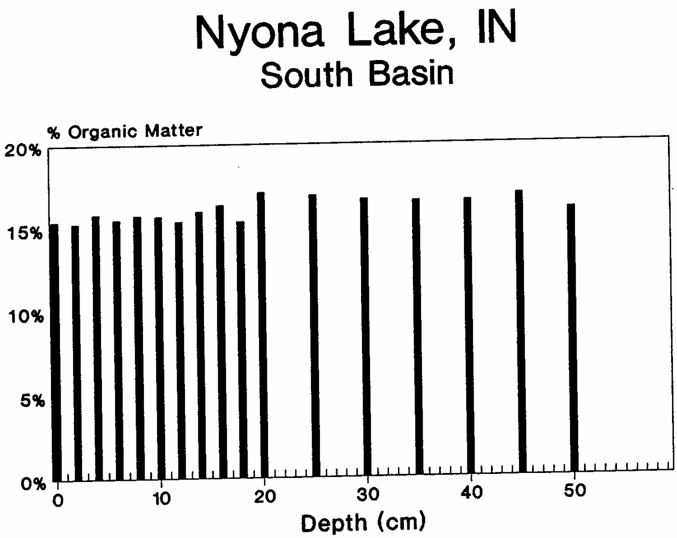
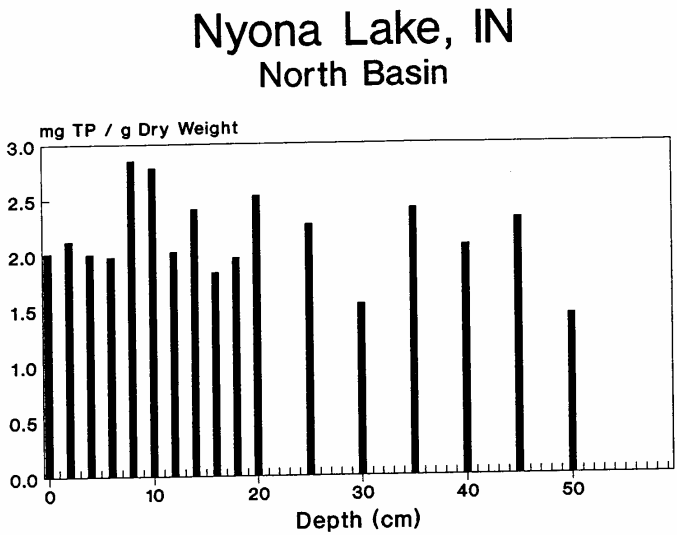


Figure 41. Profiles of Percent Organic Matter in Sediment Cores From the North and South Basins of Nyona Lake.

constant for the past century. Given that no charge was included for 210-Pb dating in our budget and this parameter was to be used only if a pronounced stratigraphy was noted, we have not included such a dating technique. Instead, we have relied on indirect estimation of sedimentation in Nyona Lake via comparison of current and historical bathymetric maps and the extent of recent basin infilling.

In situations such as Nyona Lake where the percentage of inorganic and organic matter does not change appreciably along the length of a sediment core, it is conventional to express total phosphorus concentrations as a function of the total dry weight of sediment at a particular depth in the core. In this way, deviations in the total phosphorus to sediment dry weight ratio can be used to delineate periods of past phosphorus enrichment in the lake (Figure 42). Although a great deal of intracore variability was noted, there was little consistent evidence to suggest that the total phosphorus to sediment dry weight ratio was altered in the most recently deposited sediments compared to earlier periods. Although a similar pattern was noted in the south basin, total phosphorus values in sediments of the north basin were consistently higher than those of the south basin suggesting that stream input of phosphorus far exceeds the contribution from septic tanks in urbanized watersheds such as surrounding the south basin.

The relationship between total phosphorus and sediment organic matter percentage for both the north and south basin cores is presented in Figure 43. In both cases the two parameters displayed similar trends along the length of the sediment core suggesting that phosphorus is entering Nyona Lake in a form that is easily utilized for algal and macrophyte growth.



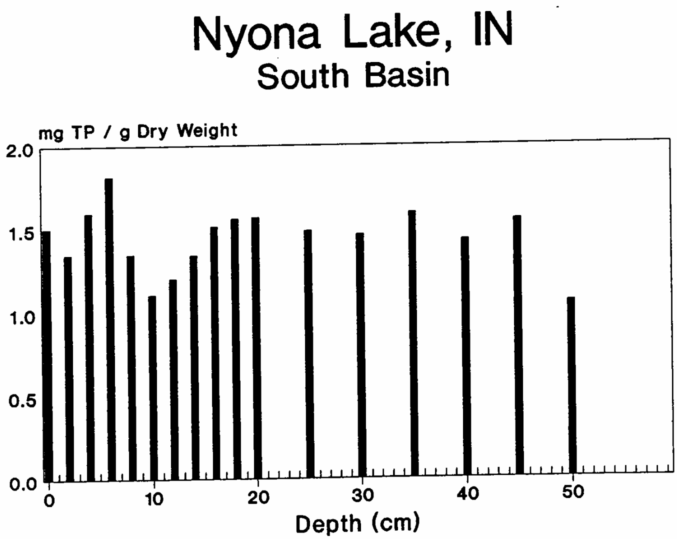
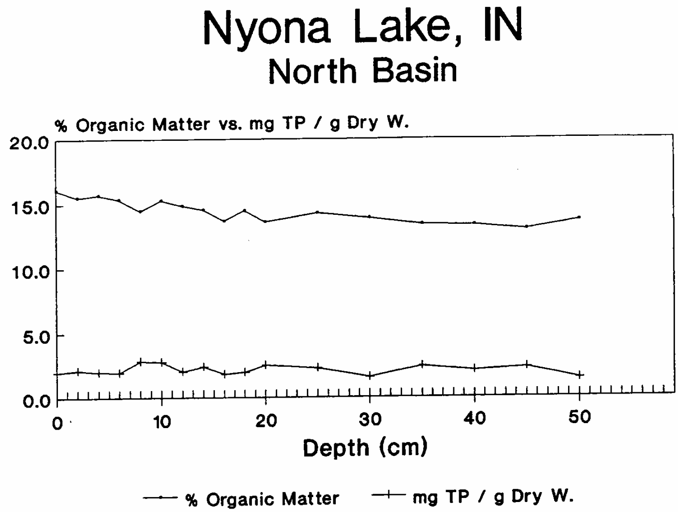


Figure 42. Profiles of Total Phosphorus Concentrations in Sediment Cores From the North and South Basins of Nyona Lake.



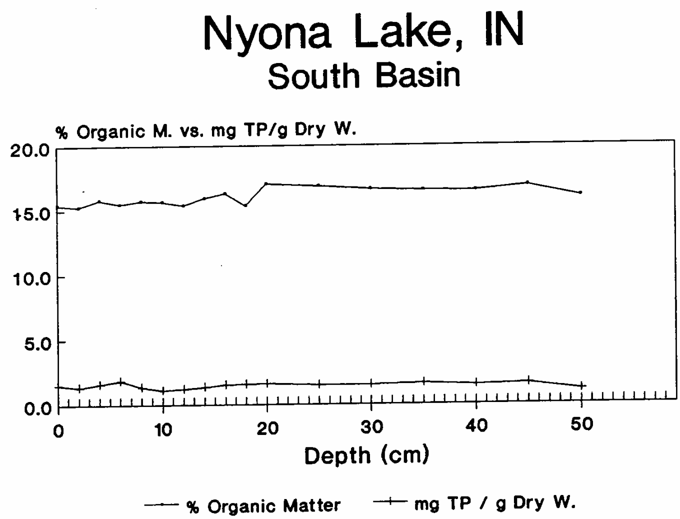


Figure 43. Comparison of Profiles of Organic Matter Percent and Total Phosphorus/Gram Sediment Dry Weight for Sediment Cores From the North and South Basin of Nyona Lake.

South
Mud Lake 2.

SOUTH MUD LAKE

Introduction

South Mud Lake (figure page ii), Fulton County, is a 94 acre lake with a maximum and mean depth of 20 feet and 10.9 feet, respectively. Legal lake level is 793.42 feet and is controlled by a concrete dam at the outlet into the South Branch of Mud Creek. The lake has two permanent inlets. Rannels Ditch drains the largest area of the watershed and enters the lake at the southeastern corner after passing through a wooded wetland. Zanger Ditch drains the southwestern portion of the watershed and enters the lake at the southwest corner after passing through a wooded wetland.

The present study was initiated because of lake residents concerns regarding excessive submergent weed and algal growth and observation of siltation associated with delivery of erosion products from the watershed especially during early spring rains.

The current chapter is designed to define the current water quality of South Mud Lake and to determine whether current values represent a marked decline in water quality within the historical past. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on water quality for South Mud Lake. The second section summarizes the water quality analyses conducted as part of the present study and compares values to earlier studies. The third and final section details our sediment studies at South Mud Lake where we were interested in determining the extent of basin infilling in the historical past as well as changes in phosphorus loading to the lake. Management implications of our analysis of past and current water quality will be discussed later in this report.

Historical Water Quality

Database

A total of 11 separate studies were conducted at South Mud Lake between 1948 and 1984 for which data were available (Table 13). The United States Geological Survey constructed a bathymetric map for South Mud Lake in 1948, but collection of water quality data on the lake did not begin until 1965. The Indiana Department of Natural Resources surveyed the fish community 7 times after 1965 and in several of these surveys included data on water chemistry and macrophytes. The Indiana State Board of Health visited the lake once in

Table 13. Chronology of Investigations at South Mud Lake

1948	United States Geological Survey. Construction of bathymetric map for South Mud Lake.
1965	Indiana Department of Natural Resources. Survey of fish community.
1966	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters.
1970	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1973	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1975	Indiana State Board of Health. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
1980	Indiana Department of Natural Resources. Survey of fish community, macrophyte composition.
1981	Indiana Department of Natural Resources. Stock lake with 470 tiger muskellunge.
1982	Indiana Department of Natural Resources. Survey of fish community.
1983	Indiana Department of Natural Resources. Stock lake with 470 tiger muskellunge.
1984	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters.

the mid-1970's to collect water chemistry and select biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state. No other data were found in the files of state and federal agencies or as research projects conducted by universities of the state.

Physical/Chemical Parameters

A total of six physical and chemical parameters have been measured at South Mud Lake at a frequent enough interval to be useful in delineating historical trends (Table 14). Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer, it is likely that they reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature. Thus, it is only valid to make interyear comparisons for individual months. The Secchi value for May 1989 (8.3 feet) was the highest transparency reading ever recorded. Unfortunately all previous readings were collected during June-August and thus can not be used for establishing intramonthly historical trends. It is normal for May values in a lake to be higher than during summer because algal populations are generally lower in late spring. The July reading for 1989 (3.12 feet) was lower than recorded in July 1966 but slightly greater than recorded during July 1970. Finally, the mean Secchi value for the two sampling dates of 1989 (Figure 44) was greater than values recorded on all previous occasions. As will be discussed later in this chapter, this recent increase in water clarity may not reflect an improvement in water quality, but may result from expansion of submergent weed growth to a point that it can effectively compete with algae for nutrients in the water column. The end result would be fewer algae suspended in the water column and clearer water.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production (Table 14). With the exception of July 1970, midsummer mean oxygen values in the water column of South Mud Lake historically have remained above 5.0 mg/L. Values for 1989 appear to be within the range expected for the lake during at least the past 23 years.

A good measure of the extent of eutrophication is provided by the extent of water column anoxia in mid summer (Table 15). The historical data suggest that although the water column of South Mud Lake during May is still oxygenated, by June it is devoid of oxygen below a depth of

Table 14. Historical Changes in Physical and Chemical Parameters at South Mud Lake for the Period 1964-1987.

Historical Data		July 1966	July 1970	June 1973	August 1975	August 1984
Secchi	feet	4	2.5	1.5	1	
Mean Dissolved Oxygen	mg/L	5.05	3.56	7.8		5.96
Alkalinity	mg/L as CaCO3		187	204		
pH		8.5	8	8.2		
Ca	mg/L		154			
Fe	mg/L		0.01			
K	mg/L	2	2			
Mg	mg/L		106			
Mn	mg/L	0.03	0.03			
Na	mg/L	4	4			
Cl	mg/L		15			
SO4	mg/L	205	68			
Total Phosphorus	mg/L		0.2	0.11	0.25	
Ortho Phosphorus	mg/L					
Nitrate-N	mg/L		0.2	0.6		
Ammonia-Nitrogen	mg/L					
Total Kjeldahl N	mg/L					
Nitrite-Nitrate	mg/L					
Chlorophyll	mg/m3					

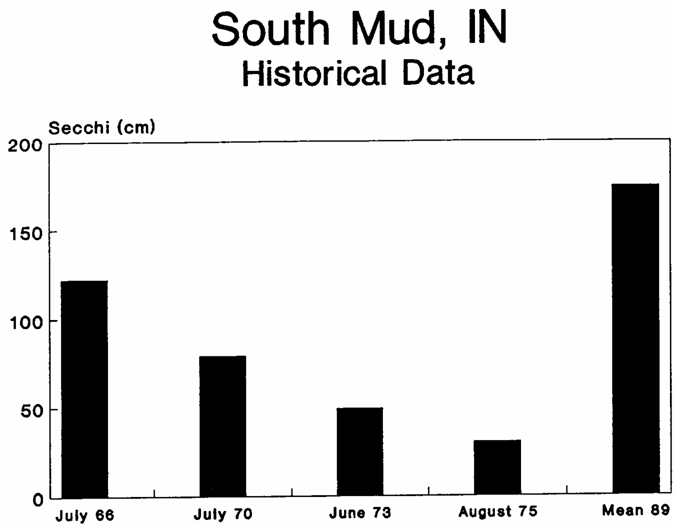


Figure 44. Historical Secchi Disk Readings in South Mud Lake for the Period 1965-1989.

Table 15. Historical Records of Water Column Anoxia in South Mud Lake, IN

Observation	Initial Depth of <1 mg/L Dissolved Oxygen
May:	
1989	DO to bottom
June:	
1973	15 feet
July:	
1966	15 feet
1970	15 feet
1989	10 feet
August:	
1984	>20 feet

15 feet. The depth to anoxia during July either remains stationary at 15 feet or even moves closer to the surface as evidenced by the 10 foot reading for 1989. The data for 1989 are consistent with trends established in previous investigations. Finally, it should be noted that although the mean dissolved oxygen value for South Mud Lake is usually greater than 5 mg/L, this is dictated by the high algal production in surface waters overlying anoxic bottom waters during summer.

Total alkalinity, a measure of the carbonate buffering capacity of lakes, increased between 1964 and 1973 but declined again in 1989 to the lowest recorded level of the 35 year period (Table 14, Figure 45). A similar pattern has been observed in Nyona Lake and other northern Indiana lakes (Crisman 1987) and has been attributed to increased delivery of carbonates from the watershed via soil erosion and leaching processes. It is highly unlikely that domestic sewage from the residences surrounding the lake had any appreciable impact on this parameter. As will be discussed later, alkalinity is but one of many parameters that record the impact of agricultural practices on water quality. The somewhat lower total alkalinity values recorded during 1989 may represent a residual effect of the drought of 1988 rather than any long term change in carbonate delivery to the lake.

Although the remaining physical and chemical parameters were sampled too infrequently to provide any historical perspective (Table 14), examination of the limited database for total phosphorus suggested that current phosphorus values may be lower than at any other time of the 35 year database (Figure 46). It is likely that phosphorus loading to the lake has not decreased, rather nutrient uptake by the accelerated expansion of submergent macrophytes in recent years has proven effective at depleting water column phosphorus levels. No previous survey attempted to evaluate whether photosynthesis in South Mud Lake was nitrogen or phosphorus limited.

Microbiology

No microbiological data for South Mud Lake were found in the files of the Fulton County Health Department or the Indiana State Board of Health.

Phytoplankton

Phytoplankton samples have been collected only once as part of the Indiana Board of Health survey in the summer of 1975. Unfortunately, we were not able to locate the original

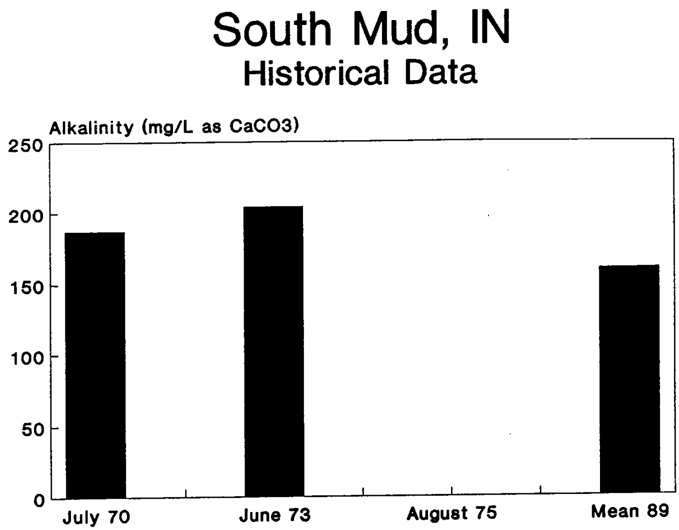


Figure 45. Historical Alkalinity Readings in South Mud Lake for the Period 1970-1989.

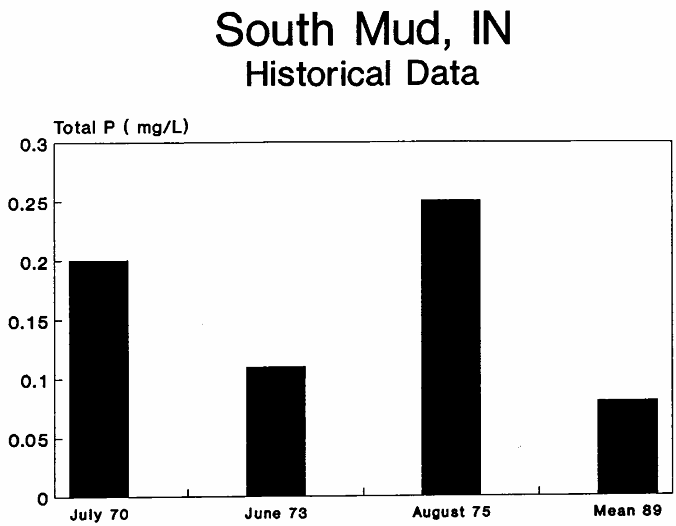


Figure 46. Historical Total Phosphorus Concentrations in South Mud Lake for the Period 1970-1989.

data in the files of the Indiana Department of Environmental Management, where the 1975 database resides.

Macrophytes

The macrophyte (aquatic weed) community was examined three times during Indiana Department of Natural Resources fish surveys conducted between 1970 and 1980. The greatest diversity of taxa recorded has always been for the submergent community (Table 16). Three pondweed species were recorded and shared dominance with water milfoil and coontail. The remaining communities, emergents, and floating-leaved historically have been represented by four and two taxa, respectively. It is interesting to note that the species composition of the entire weed community appears to have changed little between 1970 and 1980.

As early as 1970, the DNR noted that aquatic weeds were abundant in South Mud Lake. Watermilfoil was identified as the dominant submergent species. Although submergent plants were considered a problem, plant growth was considered sparse at greater than 5 feet water depth. It was suggested that the abundant plant growth offered excessive cover for panfish and that the plumpness and growth rate of the fish population could be improved through initiation of a plant control program by the lake residents. The results and recommendations from the 1973 and 1980 surveys were identical with those of the 1970 survey.

Fish

The Indiana Department of Natural Resources surveyed the fish community of South Mud Lake seven times between 1965 and 1984. A listing of the individual species caught and the contribution of each to total fish abundance caught during DNR surveys from 1965-1984 is presented in Table 17. For the following discussion, it must be remembered that historical changes in the fish community are considered indicative of trends and that interyear differences in the percentage contribution of each taxon reflect to some unknown degree interyear variability in sampling methodology. Although a total of 28 taxa have been identified from South Mud Lake, bluegill, gizzard shad, largemouth bass, and white sucker have been the dominant taxa on a percentage basis for at least the past 35 years.

Sportfish condition in both the 1965 and 1966 DNR surveys was considered average to excellent with 52% of the fish collected being largemouth bass and bluegill. Although it was felt that the fishery was not in need of management, the DNR was concerned that 23% of the fish collected were considered of undesirable species. Of particular concern was

Table 16. Species Composition of the Macrophyte Community of South Mud Lake for the Period 1970-1980.

Species	Common Name	1970	1974	1980
SUBMERGENTS:				
Ceratophyllum demersum	coontail	x		
Chara spp.	chara	x	x	x
Myriophyllum verticillatum	water milfoil	x	x	x
Najas flexilis	bushy pondweed		x	
Potomogeton amplifolius	pondweed		x	
Potomogeton crispus	curly pondweed		x	x
Potomogeton pectinatus	sago pondweed	x		
EMERGENTS:				
Ludwigia palustris	swamp loosestrife		x	x
Sagittaria latifolia	arrowhead	x		
Scirpus americanus	bulrush		x	x
Typha latifolia	common cattail	x	x	x
FLOATING LEAVED:				
Nuphar advena	spatterdock	x	x	x
Nymphaea tuberosa	waterlily	x	x	x

Table 17. Importance of Individual Fish Species Expressed as a Percent of Total Fish Abundance for DNR Surveys at South Mud Lake.

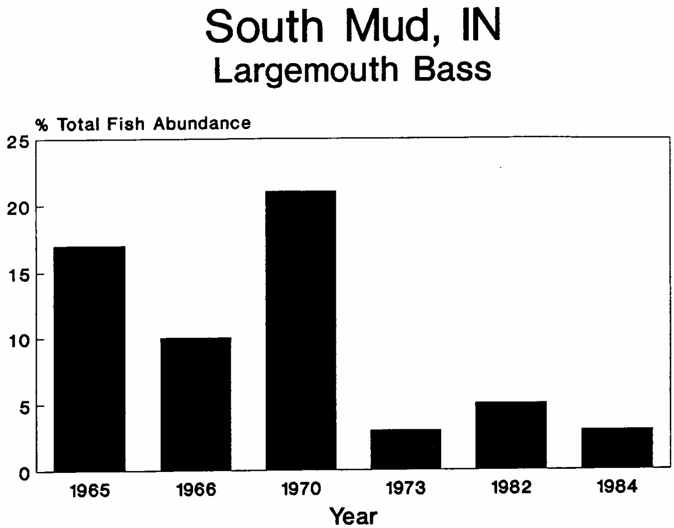
	1965	1966	1970	1973	1980	1982	1984
Black Bullhead						1.6	
Black Crappie			8.2	8		3.3	6.8
Black Redhorse						0.1	1.6
Bluegill	34.3	33.3	25.3	9.8	53.7	14.5	6
Brown Bullhead			1.1	0.8		1.8	0.1
Buffalo							0.1
Carpsucker						2.3	
Carp	9.5	6.7	0.5	0.1		0.1	0.1
Gizzard Shad	2.1	6.7	15.6	55.2		36.6	39.9
Golden Redhorse				0.5			
Golden Shiner			1.9	0.9	5.8	6.3	3.2
Hybrid Sunfish	2.5						
Lake Chubsucker				0.2			
Largemouth Bass	17.4	10	20.7	3.3	3.2	5	3.2
Longear Sunfish	2.5	11.7	0.2	0.7		0.1	
Northern Pike			0.2	0.5			
Pumpkinseed	8.3	3.3	2.5	1.3		2.1	
Quillback				0.2			0.1
Redear			0.5				
Spotted Gar	1.2		0.5	1		2.5	2
Spotted Sucker	9.9	5	0.2	2		0.1	
Tiger Muskellunge							0.1
Warmouth	0.4			0.1		0.1	
White Bass	4.1			0.5		0.1	5.6
White Crappie	2.5		3.1	2.2		0.1	0.1
White Sucker			5.6	11.3	9.8	9.8	1.2
Yellow Bullhead				0.1		0.1	0.1
Yellow Perch	5.4	23.3	12.8	1.3	9.4	9.8	25.8

the abundance of gizzard shad, which it was felt would pose future problems if it increased further.

A large largemouth bass population was recorded in 1970 and the general condition of the gamefish species was considered average. The DNR was concerned by increased abundance of both yellow perch and gizzard shad since the 1966 survey and again cautioned that these species could pose future management problems. By 1973, gizzard shad and white sucker abundance had quadrupled and doubled, respectively, over 1970 levels while yellow perch declined. Although the lake was still considered to have great fishing potential, both the abundance and condition of bluegill had decreased relative to earlier surveys. In addition, drastic declines in both largemouth bass and white bass were reported. The loss of the latter two predators was of particular concern and it was suggested that additional predator species, especially northern pike, be stocked to the lake in an attempt to control the expanding shad and sucker populations. It was also suggested to implement a 14 inch limit on largemouth bass.

The 1980 DNR survey reported that the conditions of the bluegill and largemouth bass populations were average and below average, respectively. Because of the continued large population of gizzard shad, it was recommended that tiger muskellunge be stocked as a predator species. Approximately 470 tiger muskellunge 5.8-7.6 inches long were stocked into South Mud Lake on 10 September 1981. A follow up survey by the DNR to evaluate the stocking success invested 288 hours of gill netting but failed to catch a single muskellunge. A second muskellunge stocking of 470 individuals (10.1 inch average) occured on 7 October 1983, but a follow up survey in 1984 reported only one individual (17 inches) caught in spite of over 144 hours of gill netting. The poor survival of the tiger muskellunge was in spite of abundant gizzard shad and yellow perch. It was suggested that additional stockings with muskellunge be undertaken, but with larger sized individuals.

Changes in the percentage contribution of select species to total fish abundance as recorded in the DNR surveys of 1965-1984 are summarized in Figure 47. Largemouth bass comprised 10-21% of total fish abundance between 1965 and 1970, but within the following three years had been reduced to 3% of total abundance. The contribution of this important sportfish has remained low (3-5%) during the past 16 years. The history of bluegill is similar to that of largemouth bass. The percentage contribution of this species was 25-34% of total abundance during 1965-1970, but had decreased to approximately 10% by 1973 (Figure 47). The importance of bluegill has failed to improve (6-14%) in the past 16 years.



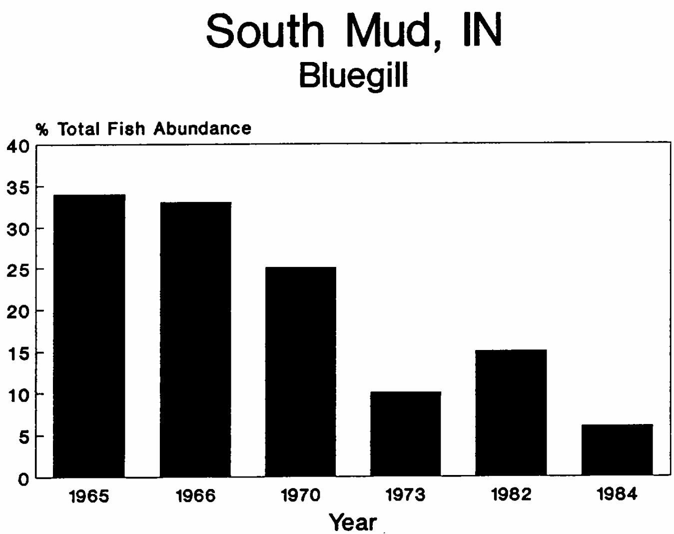


Figure 47. Changes in the Percentage Contribution of Select Species to Total Fish Abundance in South Mud Lake for the Period 1965-1984.

South Mud, IN
Shad

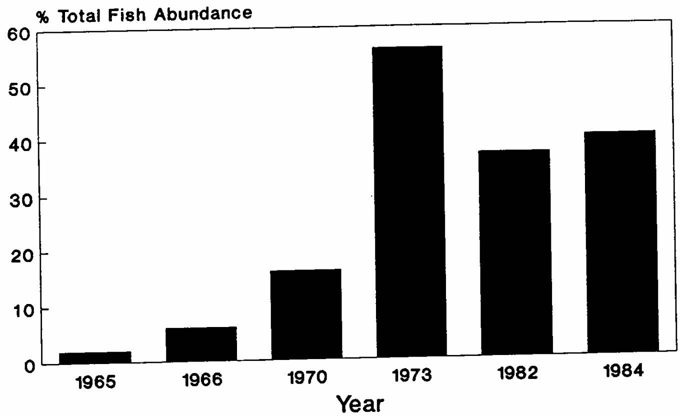


Figure 47. (Continued)

The most worrisome fishery change in South Mud Lake has been the major increase in gizzard shad that took place between 1970 and 1973 (Figure 47). From a low of 2% in 1965, this rough fish population experienced a progressive increase to 40% of total abundance in 1984, the most recent fishery survey. Such high shad levels pose potential management problems in that once established, this species promotes phytoplankton dominance through its differential digestion of other algal taxa, elevated predation on large cladoceran zooplankton, and enhanced nutrient cycling for phytoplankton utilization (Crisman and Kennedy 1982, Crisman and Beaver 1988, 1990). Such a sharp increase in shad suggests that the eutrophication of South Mud Lake may have increased steadily since 1965. Expressing the historical percentage contribution of all three species together suggests that 1970-1973 was the critical period in the fishery replacement series of South Mud Lake (Figure 48).

Current Water Quality

Introduction

Water quality parameters were collected during 1989 on 25 May and 9 July. A single sampling station was established in South Mud Lake in the area of deepest water as close to the center of the lake as possible. Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc and a Licor photometer. Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column where a Kemmerer bottle was used to collect water at each meter of the water column. All analyses were performed in certified laboratories according to EPA techniques (EPA-600/14-79-020, Methods for Chemical Analysis of Water and Wastes, Revised March 1983). Data for physical and chemical parameters for South Mud Lake during the 1989 survey are presented in Table 18.

Physical/Chemical Parameters

Temperature. Water column profiles clearly demonstrated that South Mud was thermally stratified during both May and July 1989 (Figure 49). The thermocline in May was at a depth of 5 meters, but it moved upward to 2 meters during July in response to increasing summer temperatures. The thermal regime noted for 1989 was considered typical of temperate lakes of comparable latitude.

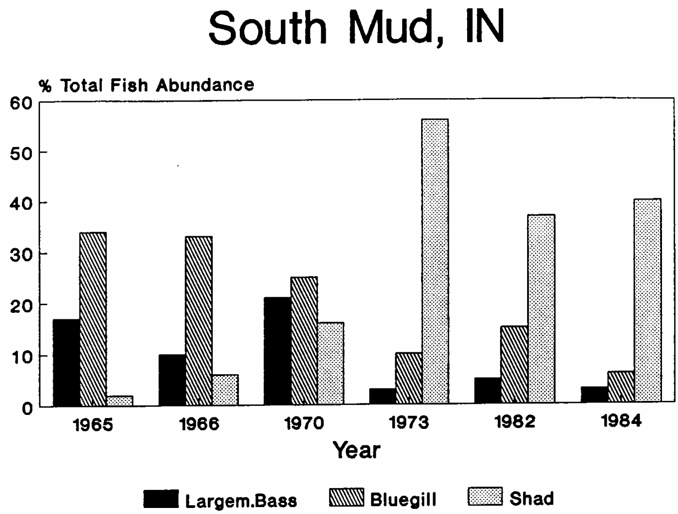
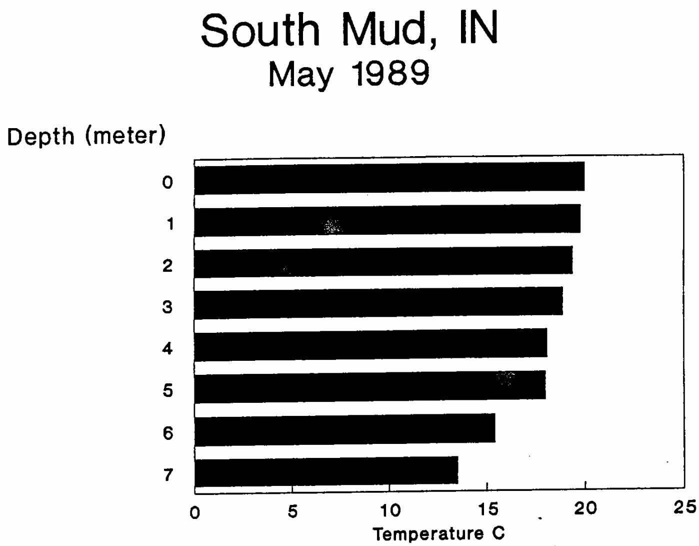


Figure 48. Percentage Contribution of Select Species to Total Fish Abundance in South Mud Lake Grouped by Year.

Table 18. Physical and Chemical Parameters for the 1989 Survey of South Mud Lake.

		25 May 1989	9 July 1989
Secchi	feet	8.3	3.12
Mean Dissolved Oxygen	mg/L	8.85	5.48
Ammonia	mg/L		0.48
Total Kjeldahl N	mg/L	3	13
Nitrite-Nitrate	mg/L	1.4	1.5
Total Phosphorus	mg/L	0.09	0.07
Ortho Phosphorus	mg/L	0.04	0.04
Conductivity	umho/cm	510	500
Alkalinity	mg/L	156	165
Chlorophyll	mg/m3	3.5	13.1



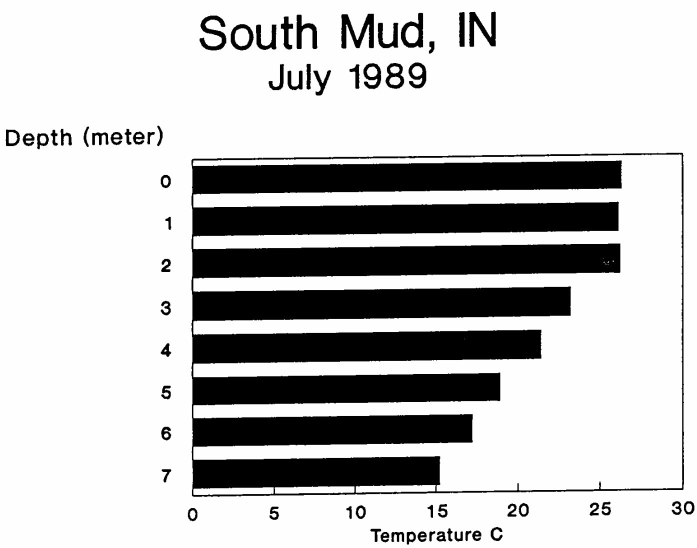


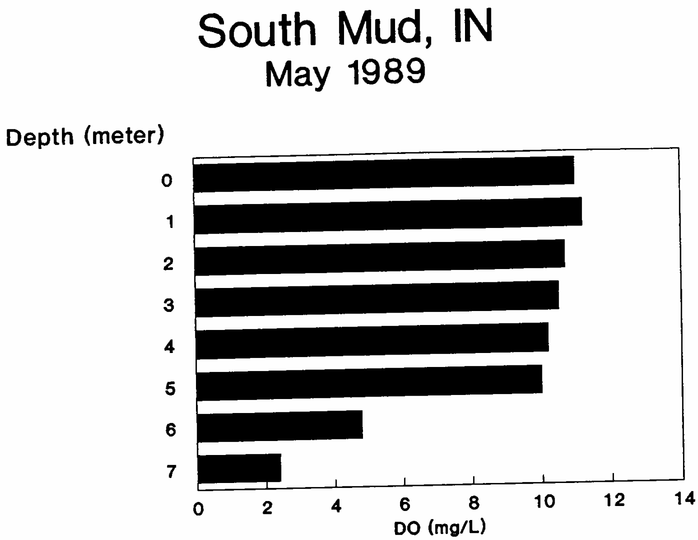
Figure 49. Water Column Temperature Profiles for South Mud Lake During May and July 1989.

Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

The lower portion of the water column (hypolimnion) of South Mud Lake displayed pronounced deoxygenation during both May and July 1989 (Figure 50). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). South Mud Lake was seriously depleted of oxygen below 5 meters in May and was essentially anoxic below 3 meters during July. Thus, even early in the stratified period of summer, the lake was displaying symptoms of severe eutrophication.

When expressed as a mean for the entire water column, dissolved oxygen was greater in May than July. The great reduction in deep water oxygen during the course of summer is a reflection of the great phytoplankton photosynthesis occuring in surficial waters. Algal organic matter that is produced by this process falls through the water column and decomposes in bottom waters. While photosynthesis adds oxygen to the surficial waters during the day, values undoubtedly decline sharply even in surface waters at nite when plants are no longer photosynthetic but are still respiring. As discussed earlier, there has been little change historically in the oxygen regime of South Mud Lake.

Secchi Disc and Photometer Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae suspended in the water column to block light transmission. Thus, the shallower the Secchi depth during midsummer, the more productive (eutrophic) a lake is presumed to be. Secchi depth declined during the course of the growing season from 8.3 feet in May to 3.12 feet in July (Figure 51). Such a decline in Secchi values in midsummer is expected in highly eutrophic lakes as phytoplankton abundance increases in response to increasing temperature and reaches levels that have a marked effect on light transmission in the water column. The July 1989 value was considerably better than the 2.5-4.0 feet recorded during July in previous surveys (Table 2). On the basis of Secchi data alone, the trophic state of South Mud Lake appears to have improved somewhat since 1975.



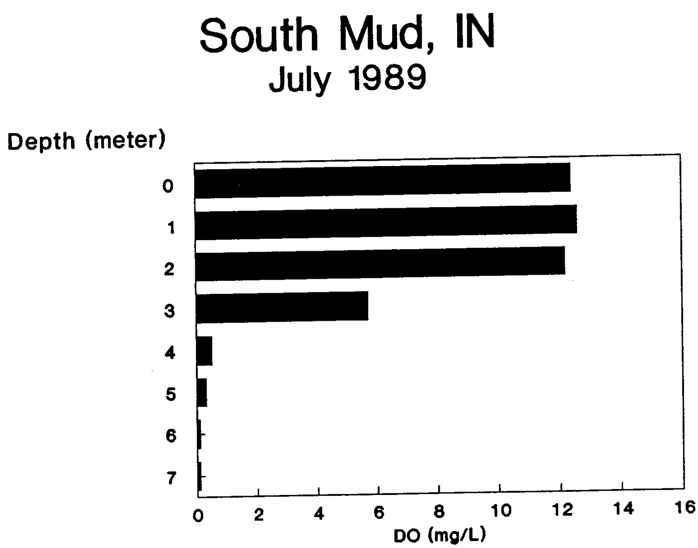


Figure 50. Dissolved Oxygen Profiles for South Mud Lake During May and July 1989.

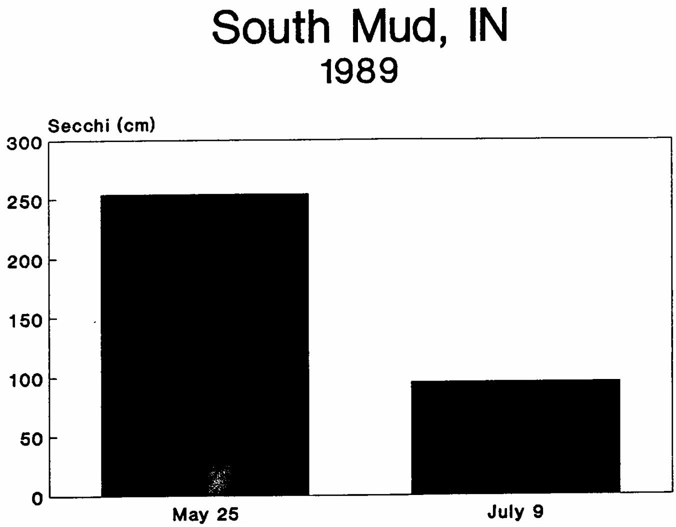


Figure 51. Secchi Disk Transparency for South Mud Lake During May and July 1989.

A Licor photometer was used on both sampling dates to estimate the depth of the photic layer in South Mud Lake. During May and July of 1989, the 1% compensation point for light was calculated as 6.3 feet and 16.6 feet, respectively. Photometer data were normally included in the ISBH statewide lake survey of 1975, but we could not find the data in the agency files for South Mud Lake.

Ammonia. Ammonia was below detection limits in South Mud Lake during May 1989, while a value of 0.48 mg/L was reported during July (Table 18). We were unable to obtain historical data for this parameter.

Nitrite-Nitrate. Values for this parameter remained relatively constant (1.4-1.5 mg/L) during 1989 (Table 18). Historical data are totally lacking for this combined parameter, but values of 0.2 and 0.6 mg/L were reported for nitrate in 1970 and 1973, respectively.

Kjeldahl Nitrogen. Values for Kjeldahl nitrogen increased markedly from 3 mg/L in May to 13 mg/L in July (Table 18, Figure 52). Historical data were lacking for this parameter.

Total Phosphorus. Total phosphorus values declined from 0.09 mg/L during May to 0.07 mg/L during July 1989 (Table 18, Figure 53). Such a midsummer decline is not unexpected. Algal and weed production should be maximal during midsummer, thus scavenging phosphorus from the water column for plant growth. In addition, phosphorus in such a thermally stratified lake would be expected to be trapped in the lower portions of the water column as algae sink and decompose.

The 1989 total phosphorus values are lower than reported (0.11-0.25 mg/L) during 1970-1975 (Table 2). While it is tempting to suggest that total phosphorus concentrations for 1989 appear to be somewhat lower that noted in earlier surveys, it is important to note, however, that water column concentrations of phosphorus are somewhat misleading estimates of trophic state. It is entirely possible that total phosphorus loading to a lake could have increased markedly between years, while water column values decreased. In lakes such as South Mud, which have experienced a pronounced increase in weeds, the phosphorus that is entering the system can be effectively trapped by the weed mass and actually decrease in the water column through effective competition with algae for this essential nutrient (Crisman 1986).

Ortho Phosphorus. Ortho phosphorus concentrations were identical on both sampling dates of 1989 (.04 mg/L) (Table 18). Historical data were lacking for this parameter.

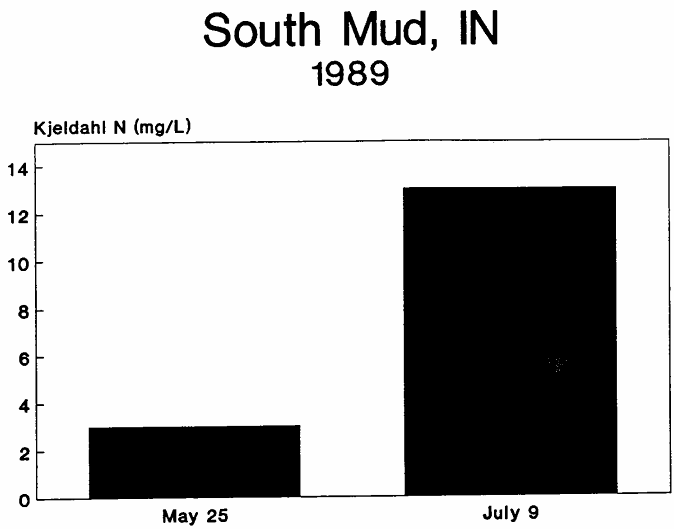


Figure 52. Kjeldahl Nitrogen Concentrations for South Mud Lake During May and July 1989.

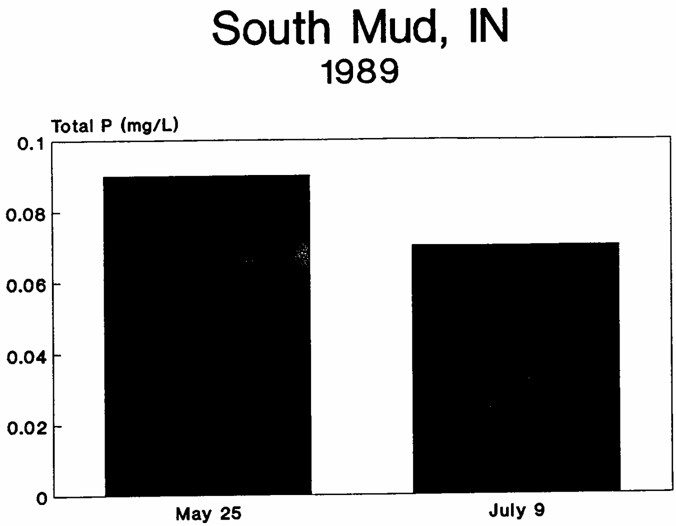


Figure 53. Total Phosphorus Concentrations for South Mud Lake During May and July 1989.

Conductivity. Values for this parameter remained relatively constant (500-510 umhos/cm) during 1989 (Table 18). No historical data for this parameter were available for comparison.

Alkalinity. Total alkalinity increased slightly (156 to 165 mg/L) between May and July 1989 (Table 18, Figure 54). As noted earlier, the 1989 total alkalinity values were lower than the 187-204 mg/L reported during the early 1970's, the only period for which historical data exist. Alkalinity is indicative of the amount of carbonate rich material dissolved in the lake water. As most of this carbonate enters the lake via watershed runoff, the data are suggestive that watershed runoff during 1989 may have been lower than the early 1970's.

Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll values in South Mud Lake increased sharply between May (3.5 mg/m^3) and July (13.1 mg/m^3) 1989 (Table 18, Figure 55) suggesting increasing phytoplankton biomass during summer. Historical data for chlorophyll were unavailable for comparison with the 1989 database. In general, however, values from South Mud Lake in 1989 generally were within the range exhibited by mesotrophic and eutrophic lakes.

ISBH Trophic State Index

Mr Harold BonHomme of the Indiana State Board of Health devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined. The Indiana Department of Environmental Management (1986) updated the database and published the most recent form of the index.

The 1975 eutrophication index for South Mud Lake was calculated by the Indiana State Board of Health as 66, thus assigning the lake to the category of poorest water quality, class III. In the current survey, we have calculated the eutrophication index for South Mud Lake based on a mean for the two sampling dates of 1989. Calculation of the index was as follows:

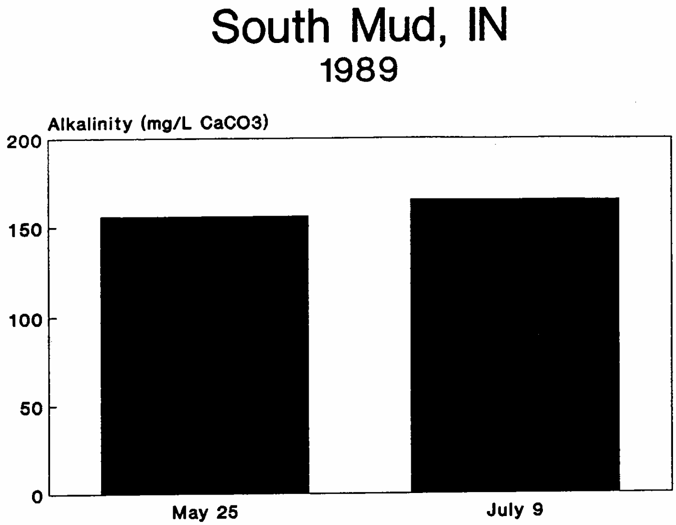


Figure 54. Alkalinity Values for South Mud Lake During May and July 1989.

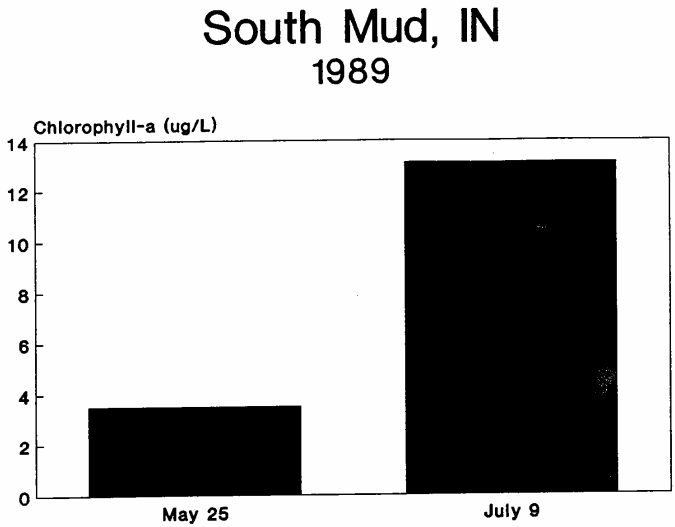


Figure 55. Chlorophyll Concentrations for South Mud Lake During May and July 1989.

Parameter and Range		1989 Value	Eutrophy Pts.
I	Total Phosphorus 0.06-0.19 ppm	0.08	3
II	Soluble Phosphorus 0.04-0.05 ppm	0.04	2
III	Organic Nitrogen 2.0 ppm or more	8.0	4
IV	Nitrate 0.9-1.9 ppm	1.45	3
V	Ammonia At least 0.3 ppm	0.24	0
VI	Dissolved Oxygen % Saturation @ 5 feet 130-149%	136	3
VII	Dissolved Oxygen % water col. with at least 0.1 ppm 76-100%	79	0
VIII	Light Penetration Secchi Disc Five feet or under	5.71	0
IX	Light Transmission Photocell: % light @ 3 feet 0-30%	30	4
X	Total Plankton per mL		
	Vertical tow from 5 feet		
	More than 10,000/mL	65,000	10
	Blue-green dominance	Yes	5
	Five foot tow including beginning of thermocline		
	30,000/mL or more	72,000	10
	Blue-green dominance	Yes	5
	Greater than 100,000/mL	No	0
	1989 Eutrophication Index		49

The 1989 eutrophication index for the lake was calculated as 49. Although algal data from the 1975 survey were not available, the summertime algal flora of South Mud Lake during 1989 was dominated by <u>Anabaena</u> and secondarily by <u>Anacystis</u> and nannoplanktonic unicellular cyanophytes.

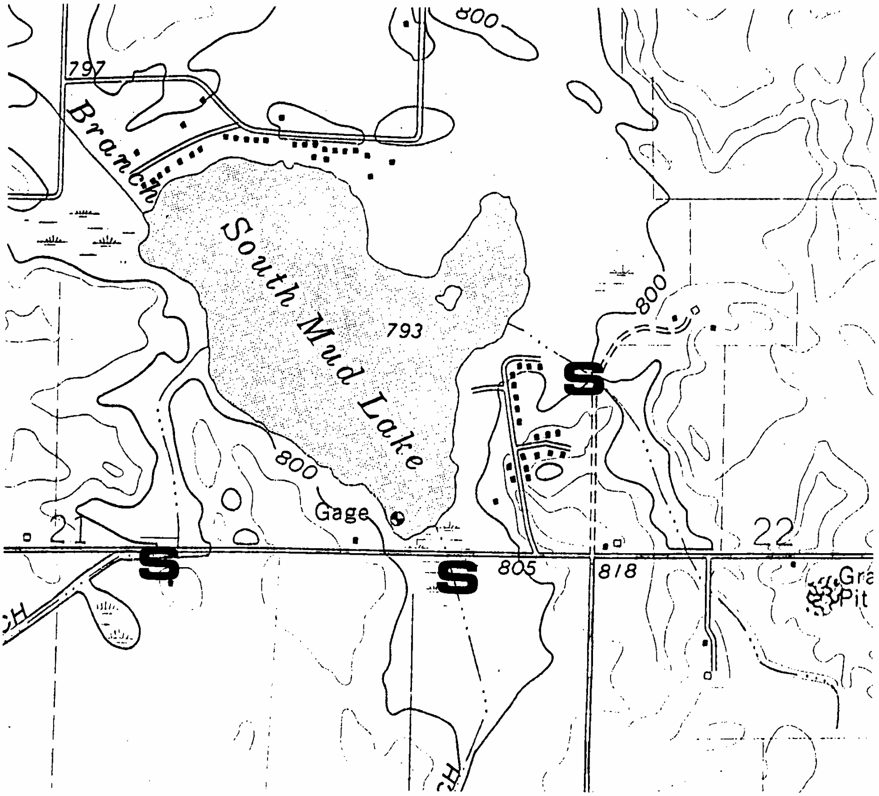
Although it is tempting to suggest that South Mud Lake is displaying better water quality in 1989 than in 1975, such an interpretation must be approached cautiously. It must be kept in mind that the eutrophication index is an estimate of the water column conditions, and like all indices, does not include the extent and productivity of aquatic weeds. Historical evidence suggests that the extent of aquatic weeds in South Mud Lake has been expanding over at least the last decade. Thus, while the overall nutrient loading to the system could have remained constant or even increased, an increasing percentage of this could have been tied up in weeds. Under these conditions, water column conditions would suggest an improvement in overall water quality, while in fact the productivity of the lake had increased, only now being largely in the form of aquatic weeds (Canfield et al 1983).

<u>Stream Chemistry</u>

Water chemistry data were collected on 17 March 1989 for three streams in the South Mud Lake watershed (Figure 56A): Zanger Ditch, Rannels Ditch, and C. Brown Ditch. The Zanger Ditch drains the southwestern portion of the South Mud Lake watershed and enters the lake along the western shore through a wooded wetland. This ditch was "cleaned" by dredging in late 1988 to improve flow, and no bank stabilization was attempted. The watershed area drained is rolling and flat terrain dedicated mainly to pasture usage. The sampling site for this ditch was from the County Road bridge near the ditch mouth.

The Rannels Ditch drains the southeastern portion of the South Mud Lake watershed, a relatively flat area used for cultivation and short pasture. Samples were collected at the County Road bridge crossing the wetland at the ditch mouth. The final inlet ditch to South Mud Lake is C. Brown Ditch which drains the eastern portion of the watershed and enters the lake at the extensive wetland along the eastern shore. This portion of the watershed has extensive areas that are relatively flat, poorly drained and wooded. Upland areas are mostly uncultivated. Water samples for C. Brown Ditch were collected immediately upstream from the inlet to South Mud where the County Road crosses the ditch.

Stream flow at the time of sample collection ranged from .071 cfs for Zanger Ditch to .422 cfs for C. Brown Ditch (Figure 56). The discharge for all three sites was considered normal for mid March.



Stream Monitoring Stations, South Mud Lake.
(Figure 56A)

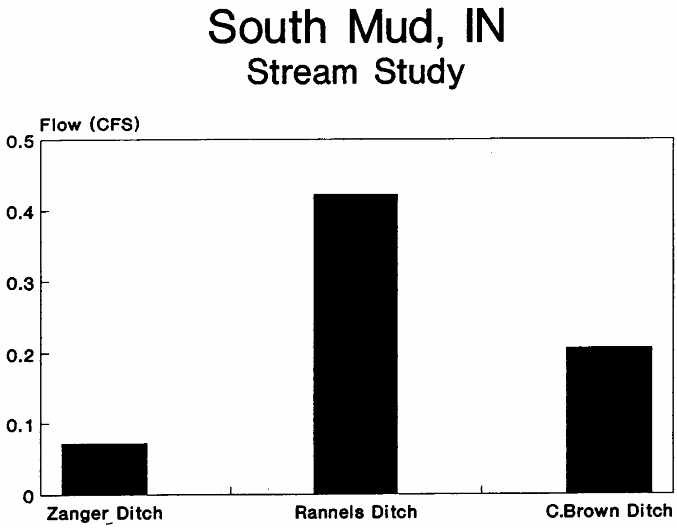


Figure 56. Flow in Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

With the exception of C. Brown Ditch, the streams had slightly acidic pH (Figure 57) with the lowest value (6.3) noted in the stream (Rannels Ditch) displaying the highest velocity flow. Total alkalinity (Figure 58) ranged from 186 to 223 mg/L with the highest value recorded at the lowest flow site (Zanger Ditch). Stream values were slightly higher than the 156-165 mg/L reported in South Mud Lake during May and July 1989. Conductivity (Figure 59) also displayed little variability between stream stations and ranged from 2,500 to 3,000 umho/cm.

Two forms of nutrients were measured at all stream stations. Nitrite/nitrate nitrogen ranged from 1.96 mg/L in C. Brown Ditch to 3.47 mg/L in Rannels Ditch (Figure 60). Total phosphorus (Figure 61) ranged from 0.08 mg/L (C. Brown Ditch) to 0.12 mg/L (Zanger Ditch). The rank ordering of the streams for total phosphorus was roughly the same noted for nitrogen and appeared not to be strongly linked with stream flow characteristics. Total phosphorus values for the stream sites were similar to the 0.07-0.09 mg/L reported for South Mud Lake in 1989 as part of the present survey. Finally, total suspended solids (TSS) ranged from 8-18 ppm (Figure 62) with the highest value reported from the stream having the lowest velocity of flow (Zanger Ditch).

Microbiology

Water samples for fecal coliform analysis were collected from South Mud Lake in conjunction with the May and July 1989 water quality investigations. Samples were analyzed within eight hours of collection. The analyses followed the state approved membrane filter procedure and counts have been expressed as most probable numbers (mpn), a standard way of estimating bacterial numbers. The concentration of fecal coliform bacteria in the lake for 25 May was 9 mpn/100 mL of water. Bacteria levels were even lower on 9 July (1 mpn/100 mL of water), barely within the limits of detection. All bacteria counts at South Mud Lake during 1989 were well within state standards. It is felt that there is not a serious fecal contamination problem in South Mud Lake.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic weeds in South Mud Lake. A total of 12 transects spanning the width of the lake were used as the data base. The plant survey was conducted in July 1989 and thus represents midsummer plant extents. Plant biovolume is defined as the percent of the water column at a given location in the lake that is filled with plant biomass. Thus, it is a measure of the extent of weed infestation

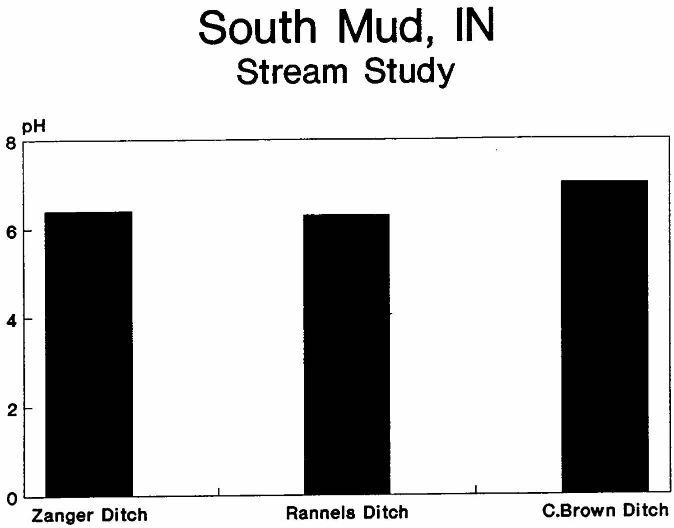


Figure 57. pH Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

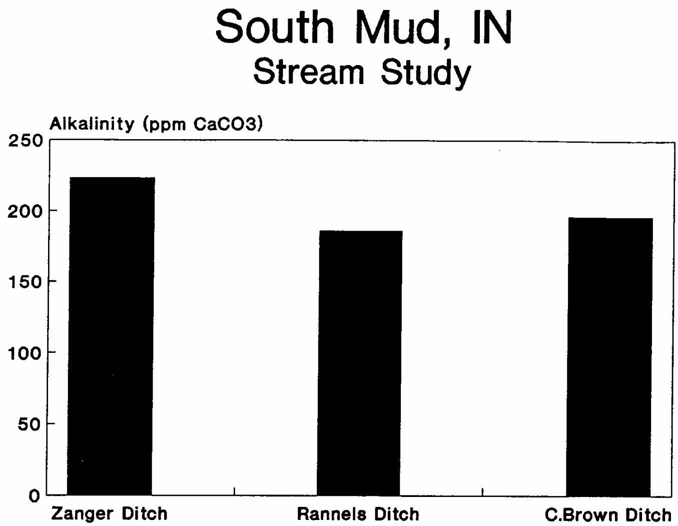


Figure 58. Alkalinity Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

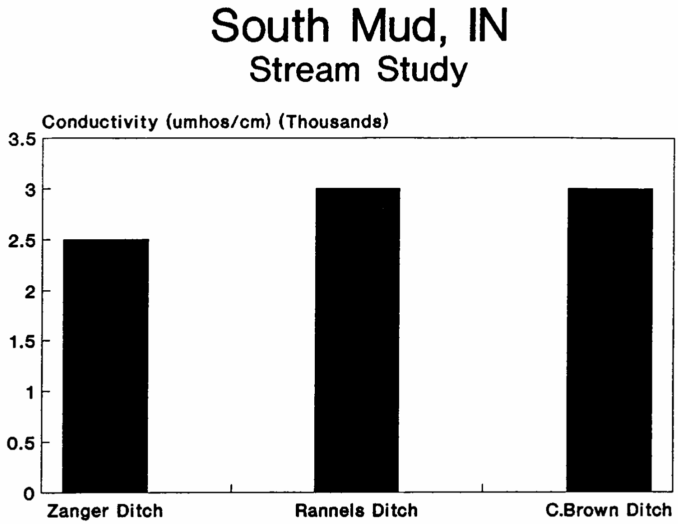


Figure 59. Conductivity Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

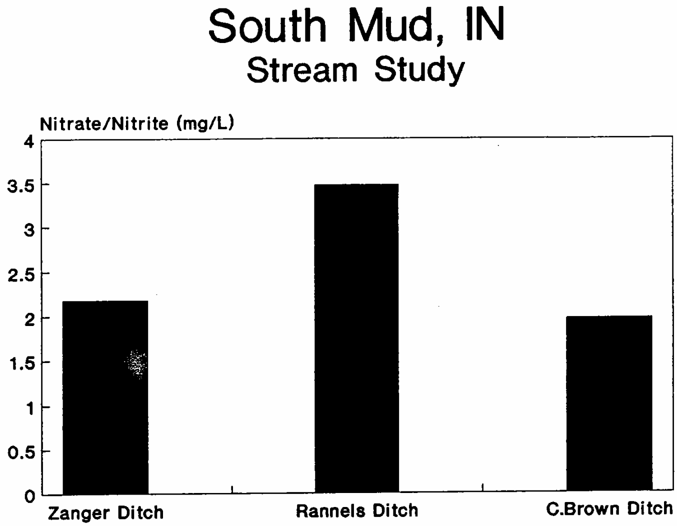


Figure 60. Nitrite/Nitrate Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

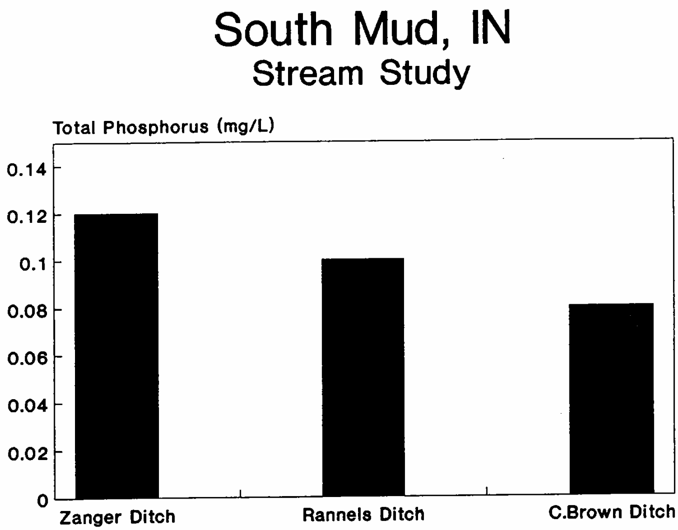


Figure 61. Total Phosphorus Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

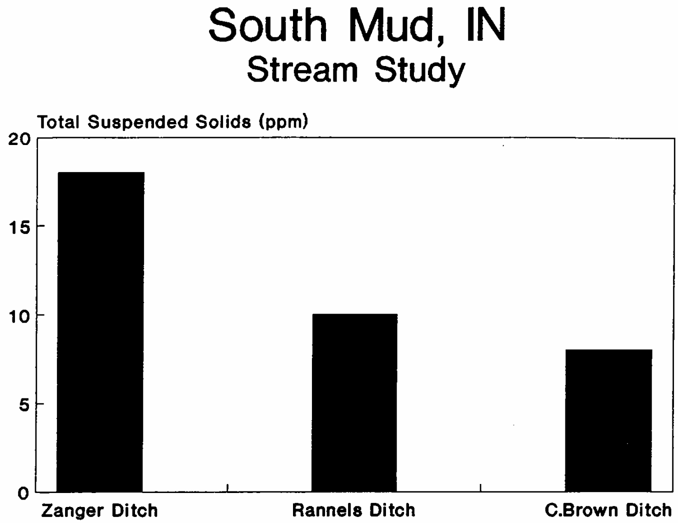


Figure 62. Total Suspended Solids Values for Three Ditches Draining the South Mud Lake Watershed for 17 March 1989.

throughout the lake system.

The distribution of plant biovolume in South Mud Lake is presented in Figure 63. This figure demonstrates the patchy distribution of plants in the lake. A much more informative way of looking at the data is to plot biovolume in increments of 20% water column infestation (Figure 64). The nearshore areas of the lake were considered 100% infested with weeds in 1989. The maximum extent of this area was in the shallow embayment in the northeastern corner of the lake where it was totally impossible to get a motor boat to the shore.

The extent of the 80% plant infestion zone was only a fraction of the 100% category and was in slightly deeper water. This zone reached its maximum aerial extent in the northwestern corner of the lake in the vicinity of the outlet. The 60%, 40% and 20% biovolume zones were greatest in the northwestern and southeastern portion of the basin, while the less than 20% and weedless zones were restricted to the deepest portions of the lake.

Aquatic plants filled 80-100% of the water column under 26.3% of South Mud Lake (Figure 65). Using 80% biovolume as the cutoff defining serious management problems, aquatic macrophytes appear to be a problem only in a narrow shoreline fringe and in the large embayment. In marked contrast, 52.8% of the lake bottom is characterized by plant biovolumes less than 20% or weedless, thus posing no management problems.

Macrophyte problems in South Mud Lake appear to be restricted to water less than 5 feet deep (Table 19). Approximately 51% of the area of the 0-5 foot depth interval is completely choked with weeds representing 23% of the total lake surface area. The results clearly demonstrate that aquatic weeds display pronounced light limitation below five feet water depth and suggest that only those areas less than this critical depth are in need of plant management.

Actual plant heights for South Mud Lake are presented in Figure 66. For clarity, the distribution of individual two foot plant height increments have been presented in Figure 67. Plant heights 4-6 feet tall were recorded only in two extremely small areas in the eastern half of the basin and are considered to have no bearing on the overall distribution of plant growth in the lake.

Plant growth 2-4 feet tall was restricted to three small patches in South Mud Lake: the shallow area near the center of the lake and near the vicinity of the inlets of Zanger and Rannels Ditches suggesting that macrophytes thrive nearest the sources of nutrient input to the lake from the watershed. A vast majority of the plant growth in

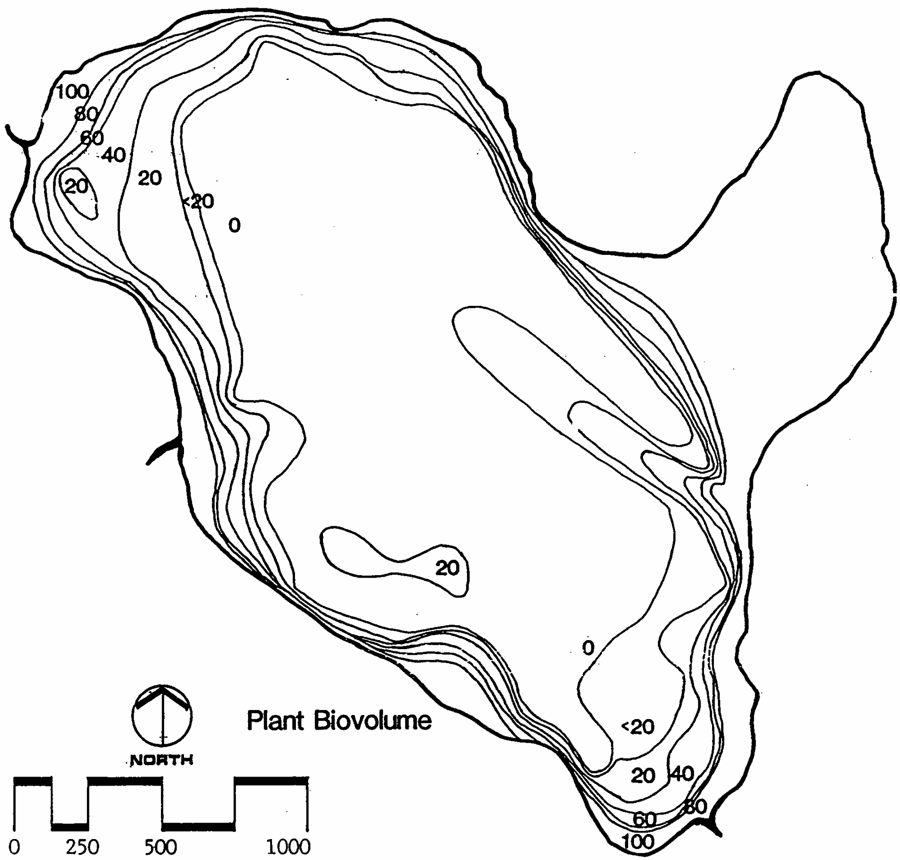


Figure 63. Distribution of Aquatic Weed Biovolume in South Mud Lake for 1989.

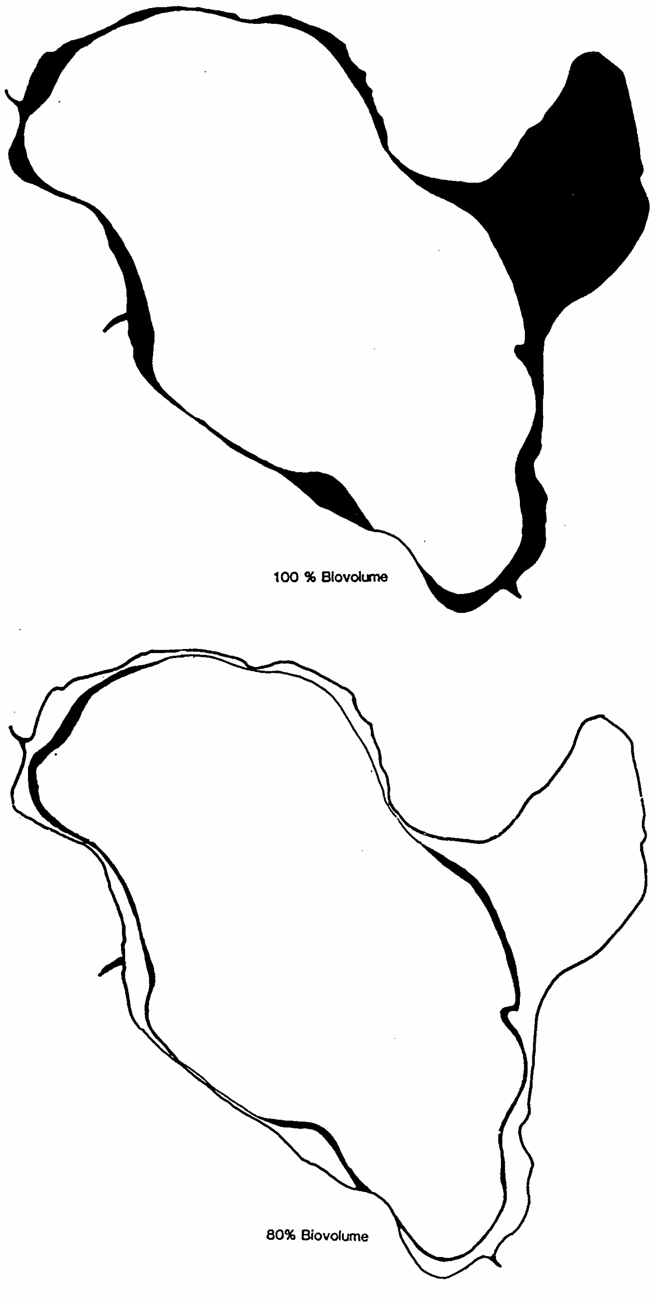
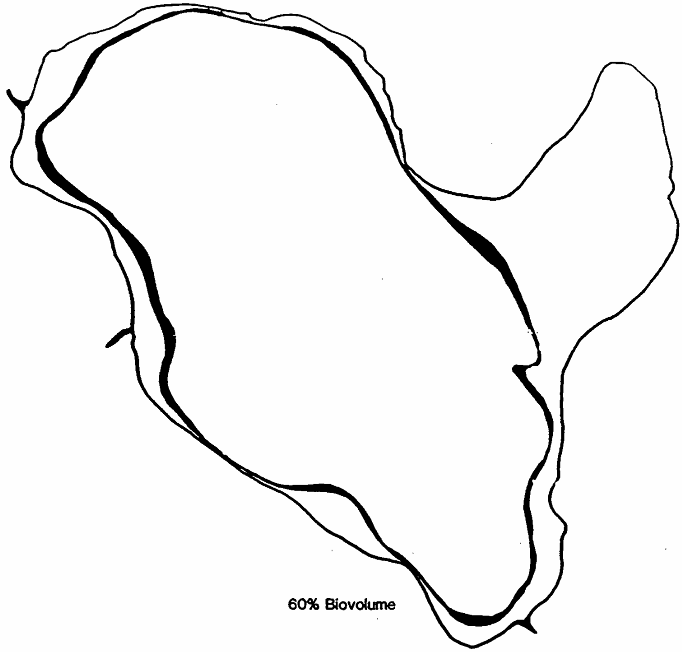


Figure 64. Plant Biovolume at South Mud Lake in Increments of 20% Water Column Infestation.



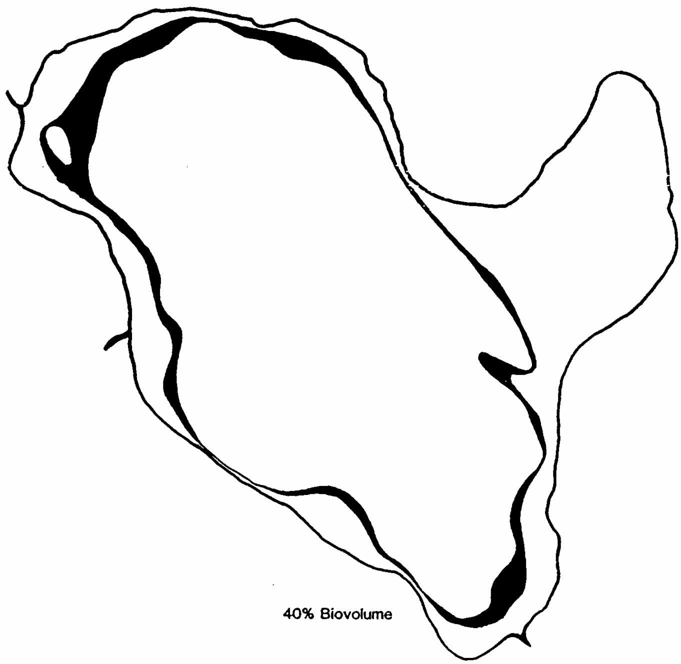
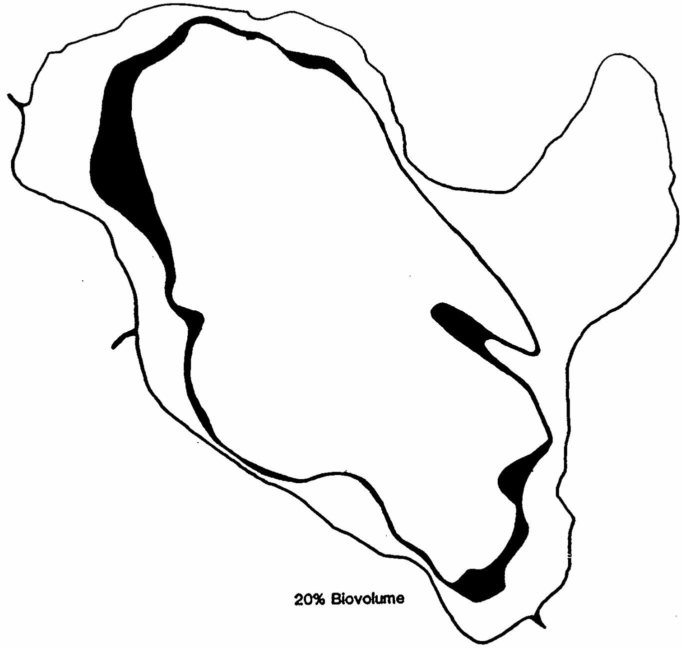


Figure 64. (Continued)



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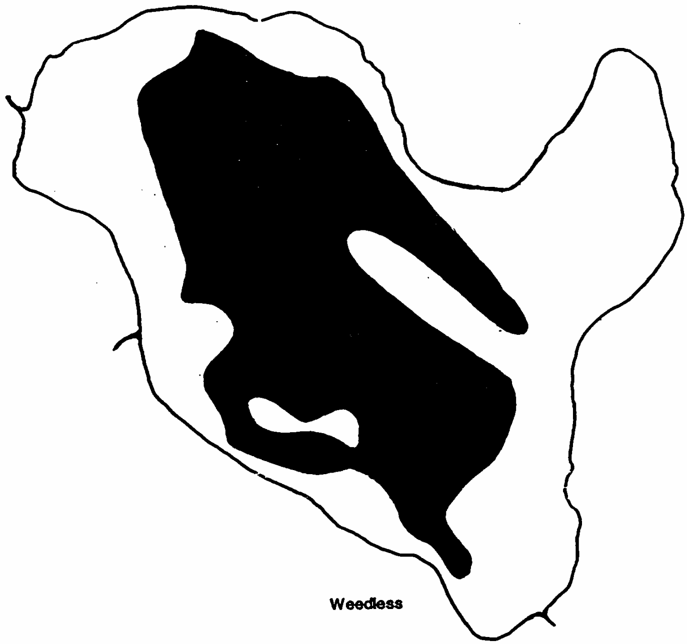

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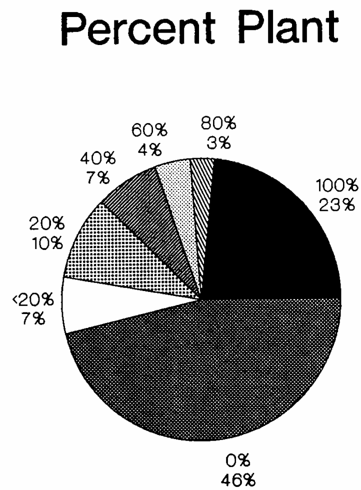


Figure 65. The Distribution of Plant Biovolume in South Mud Lake Expressed as a Percent of Water Column Infestation.

Table 19. Macrophyte biovolume (20% increments) expressed as percent aerial coverage for both individual five foot contour intervals and the entire area of South Mud Lake.

Interval	Biovolume %	Area Acres	% Area Contour Interval	% Basin Area
0-5 feet	100	23.3	51.2	23.3
	80-99	2.7	5.9	2.7
	60-80	3.8	8.4	3.8
	40-60	5.8	12.8	5.8
	20-40	2.8	6.1	2.8
	1-20	2.7	5.9	2.7
	0	4.4	9.8	4.4
5-10 feet	100	0.1	0.7	0.1
	80-99	0.1	0.7	0.1
	60-80	0.3	1.5	0.3
	40-60	1.4	7.5	1.4
	20-40	5.1	27.9	5.1
	1-20	6.1	8.5	6.1
	0	9.7	53.2	9.7
10-15 feet	100			
	80-99			
	60-80			
	40-60	0.1	0.5	0.1
	20-40	0.8	3.4	0.8
	1-20	2.3	9.3	2.3
	0	21.4	86.8	21.4
15-20 feet	100			
	80-99			
	60-80			
	40-60			
	20-40	0.8	8.1	0.8
	1-20			
	0	9.2	91.8	9.2
>20 feet	100			
	80-99			
	60-80			
	40-60			
	20-40			
	1-20			
	0	1.5	100.0	1.5

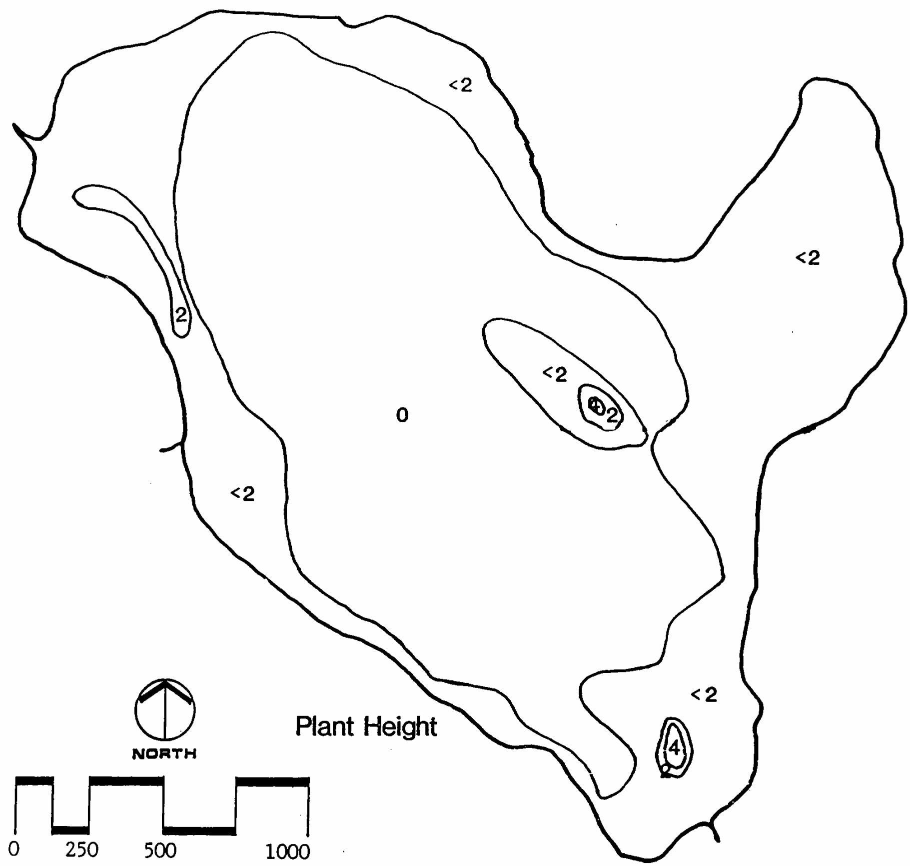


Figure 66. The Height of Aquatic Weeds in South Mud Lake in 1989.

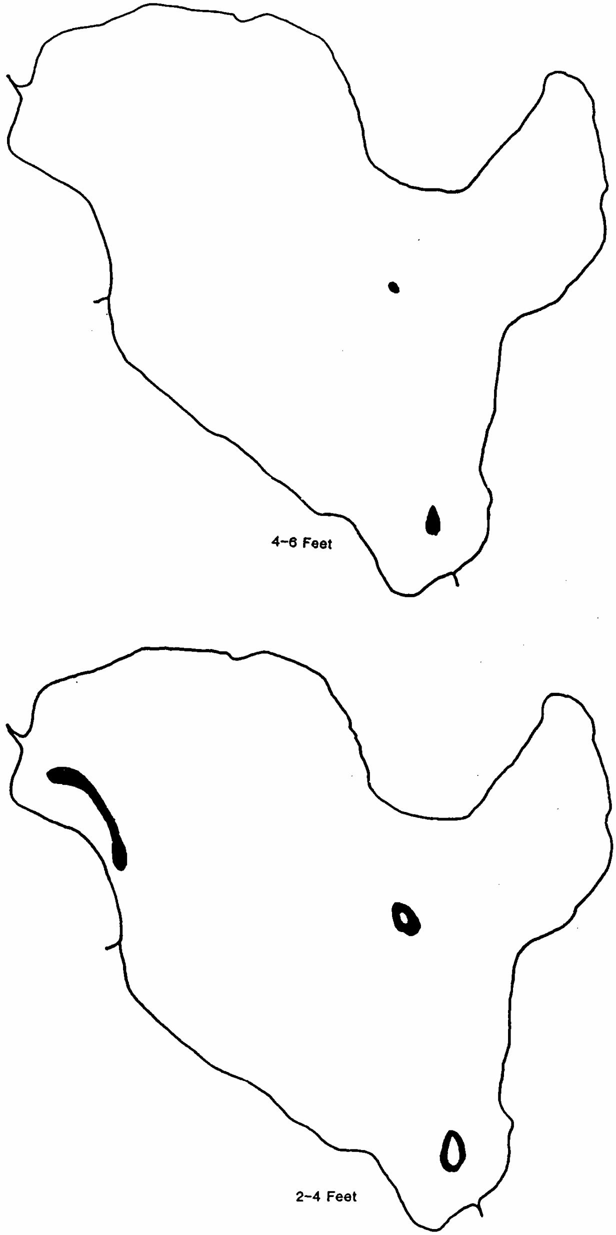


Figure 67. The Distribution of Aquatic Plant Height in South Mud Lake by 2 Foot Height Increments.

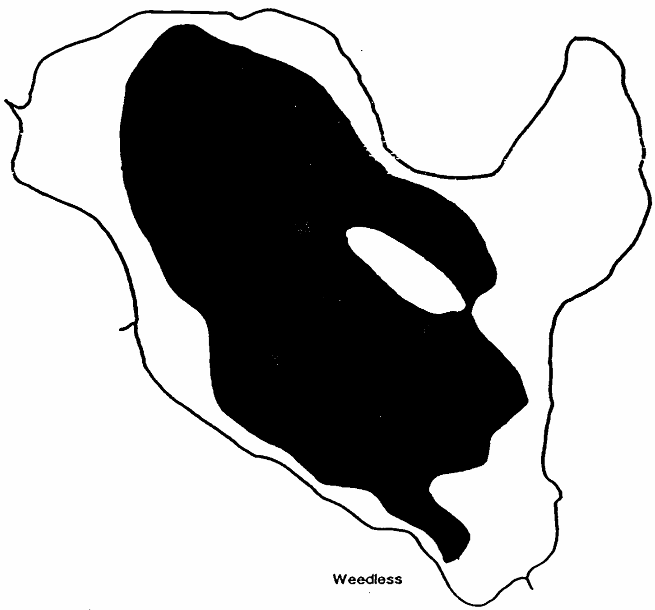


Figure 67. (Continued)

South Mud Lake was less than 2 feet tall (Figure 67). The results suggest that most weed problems along the shore are associated with short vegetation that completely fills the water column. As noted earlier, aquatic plant growth is minimal in water less than 5 feet while the deepest sections of the lake are completely weedless due to pronounced light limitation for plant growth.

In addition to looking at the distribution of plant biomass in South Mud Lake, a qualitative survey was made to determine the distribution of the major plant species in the system. Sketches of the most important macrophyte species in South Mud Lake are presented in Figure 68, and their distributions are given in Figure 69. The exotic species, Myriophyllum spicatum (Eurasian watermilfoil), was the dominant submergent plant in the lake. This plant is the principal contributor to total plant biomass and should be the target of any aquatic management program. As noted earlier for Nyona Lake, DNR survey data suggest that a native ecological equivalent, Ceratophyllum (coontail), was restricted to nearshore areas and obviously being replaced by watermilfoil in recent years. Shallow water areas along the undeveloped western and southern shores of the lake were characterized by dense growths of spatterdock (Nuphar) and water lilies (Nymphaea). Residential development along the northern shore likely promoted destruction of these plants. The dense Nuphar growth near stream inlets is likely serving a beneficial purpose in trapping some of the nutrients and silt delivered by inflowing ditches. The embayment along the eastern shore is almost completely dominated by cattails (Typha), and it is impossible to get a boat through this area.

As early as 1965, the DNR reported major destruction of aquatic macrophytes along the southwestern shore of South Mud Lake by cattle pastured in the immediate watershed and permitted to water directly in the lake. It was reported further that "large" amounts of silt washed into the lake from this pastured shoreline during rainy periods as a direct consequence of cattle induced shoreline erosion. It was suggested that a fence be erected to keep the cattle away from the shore. The problem was still apparent in 1989 and in addition to promoting destruction of vegetated areas and increased delivery of sediment to the lake, is considered one of the major nutrient loaders to the lake via direct cattle defecation into the water.

Fish

The Raytheon fathometer data recorded from the 12 cross lake transects were also used to provide a qualitative assessment of the fish community of South Mud Lake. Echos of fish in the water column appear on all fathometer

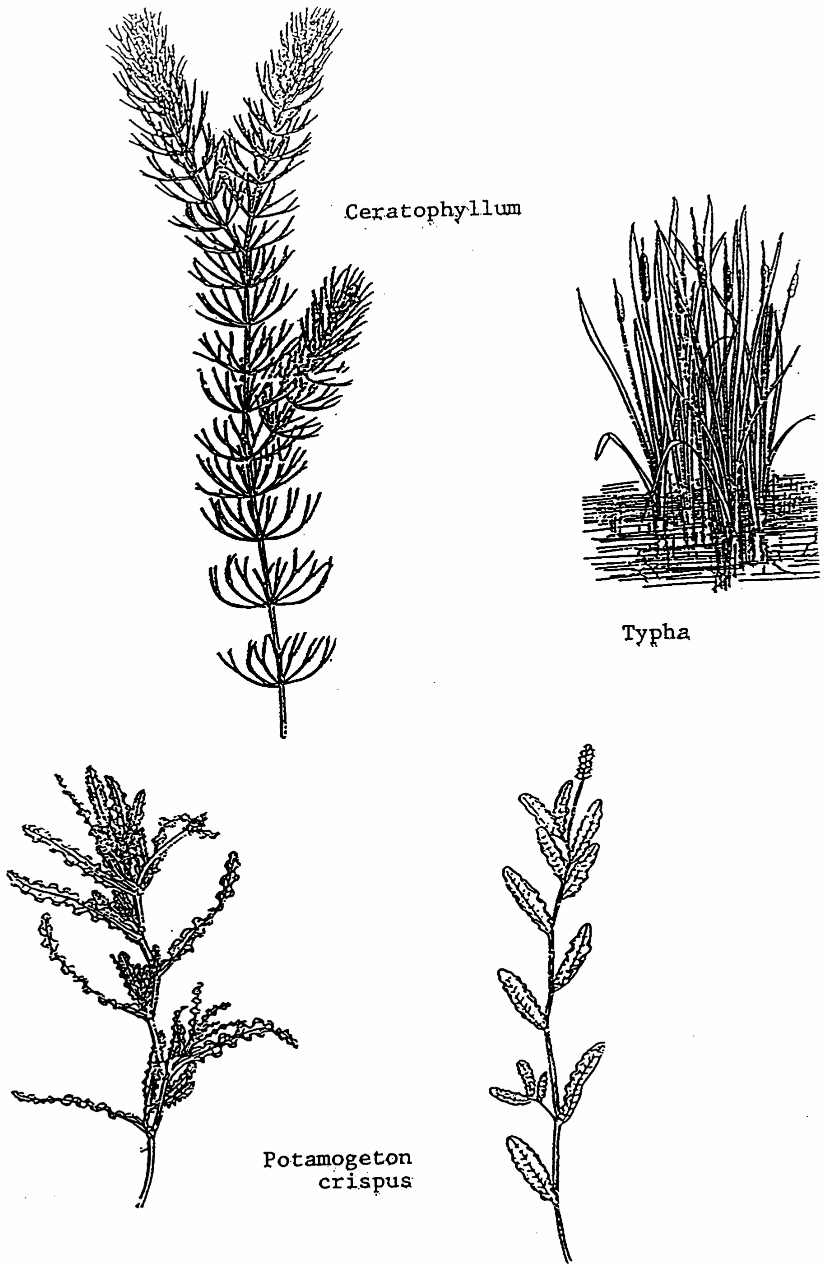


Figure 68. Common Plant Taxa Found in South Mud Lake during 1989. Drawings adapted from Fassett (1940) and Correll and Correll (1972).

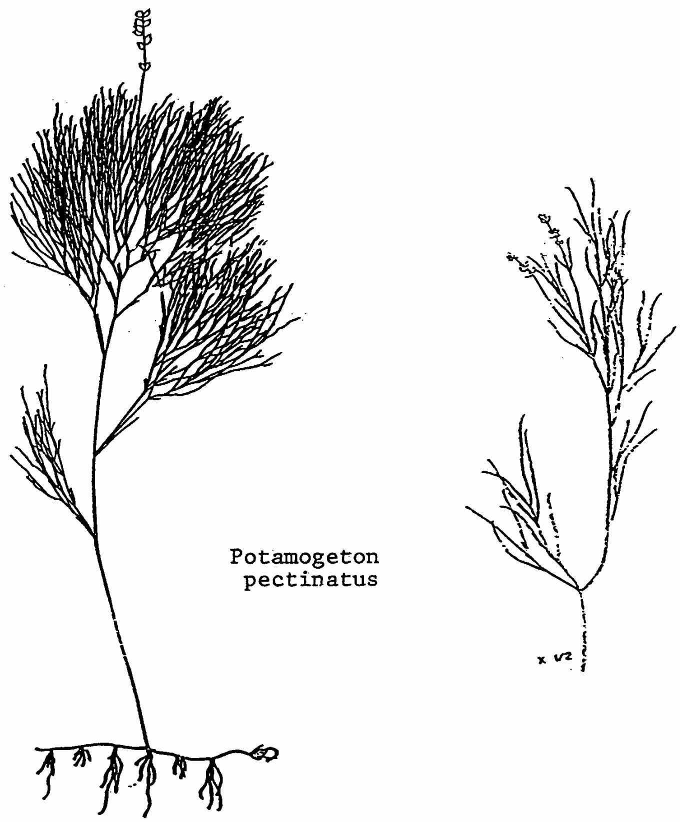
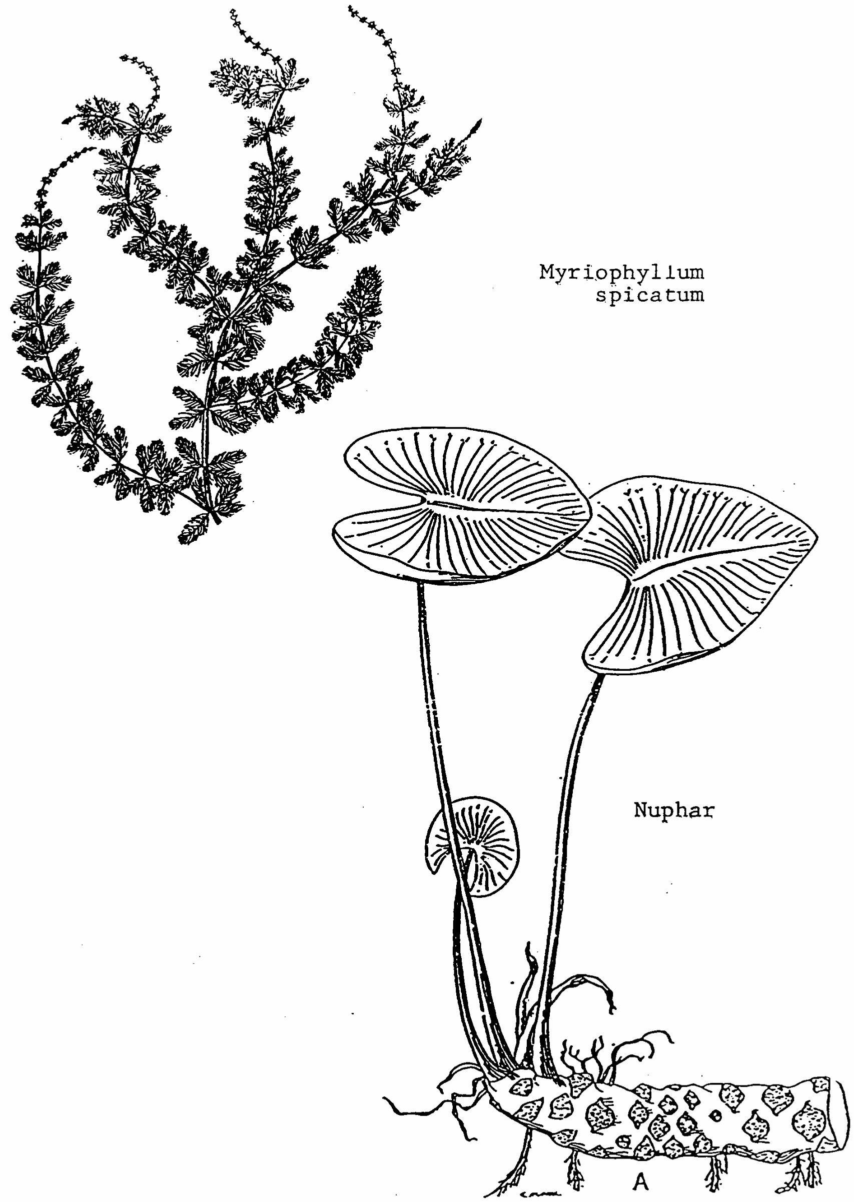


Figure 68. (Continued)



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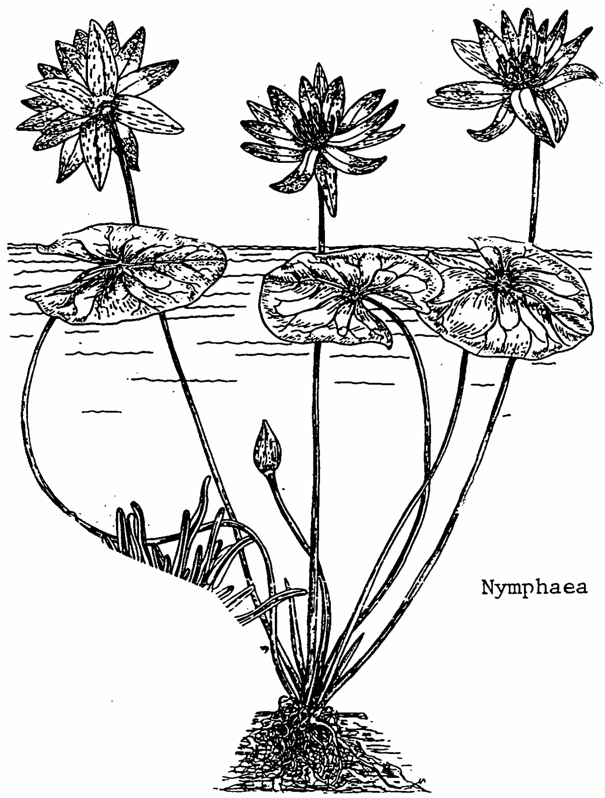

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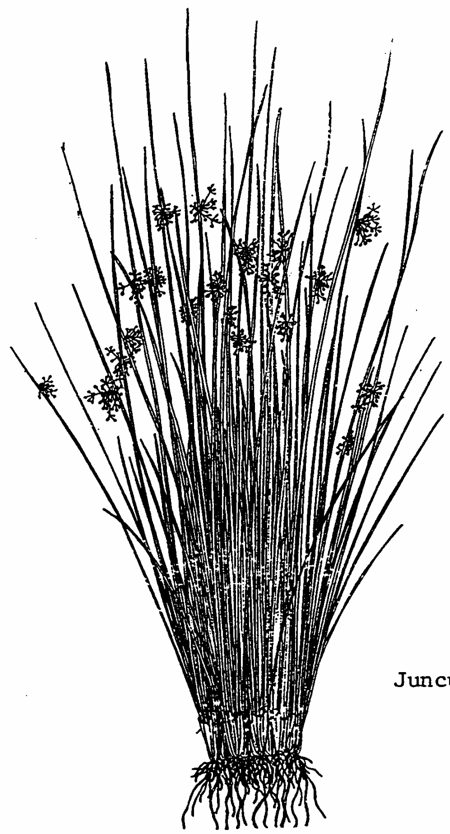

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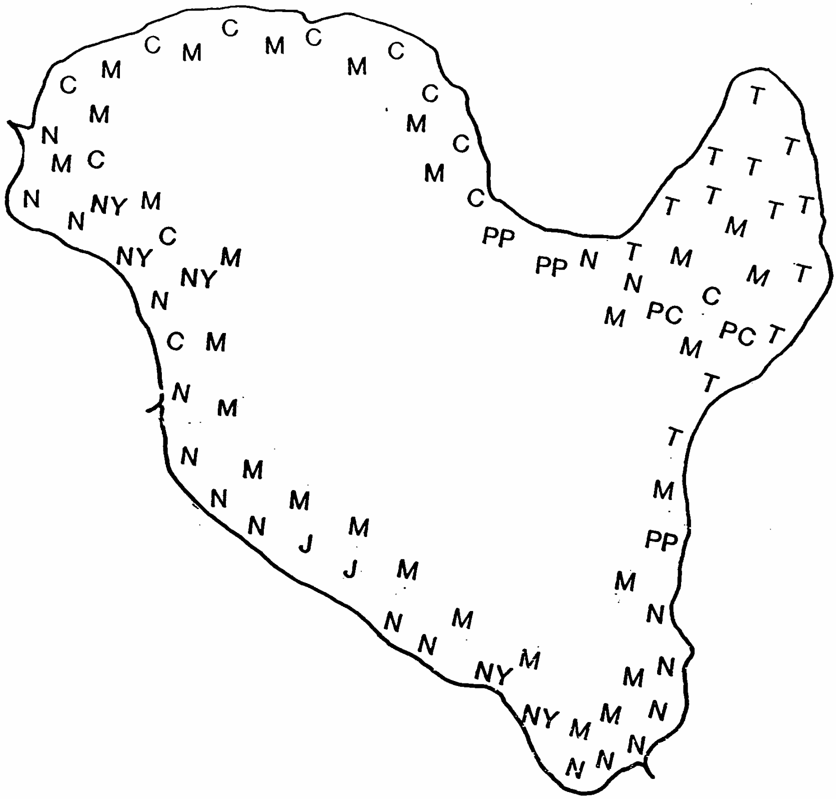


Figure 69. Distribution of Major Plant Taxa in South Mud Lake in 1989. Plants were: Ceratophyllum (C), Juncus (J), Myriophyllum (M), Nuphar (N), Nymphaea (NY), Potamogeton crispus (PC), Potamogeton pectinatus (PP), and Typha (T).

recordings, and these were used to assess total fish abundance and the depth distribution of the population for the lake.

Fish data have been presented on the basis of number individuals per 1000 feet of fathometer transect (Figure 70). Total fish abundance in open water areas of South Mud Lake was estimated at 32/1000 feet of transect and is in a comparable range as those of the north (45/1000 feet transect) and south (34/1000 feet transect) basins of Nyona Lake.

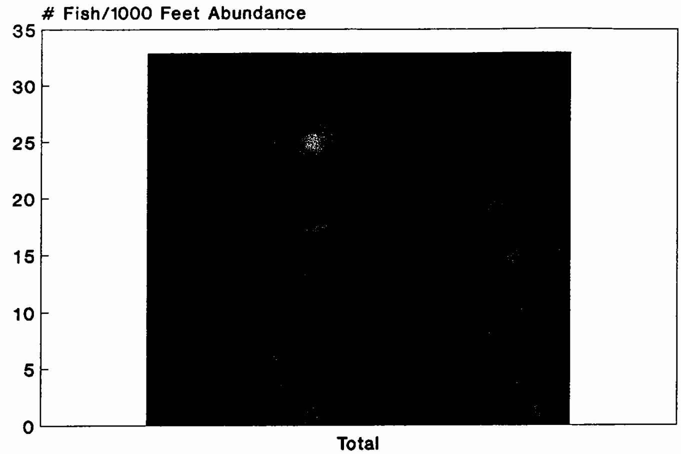
The greatest density of fish (48% total abundance) was at a depth of 3-5 feet (Figure 71). Fish avoided shallower water, the area of highest water temperatures. Unlike Nyona Lake, a second, although reduced, peak in total fish abundance was noted at depth of 13-17 feet. The latter is particularly interesting in light of the fact that oxygen values are rapidly approaching zero below 11 feet. If trophic state continues to increase, this deeper water population will eventually be forced to live in warmer surface waters. It must be noted, however, that oxygen is only one of many factors controlling fish distributions. The dense weeds at depths less than 10 feet may exclude many fish. Effective reduction in plant biomass will likely open new habitats for both feeding and reproduction.

Bathymetric Map and Lake Infilling

The Indiana DNR in association with the United States Geological Survey published a bathymetric map of South Mud Lake based on a survey of 1948 (Figure 72). Depth contours were constructed at five foot intervals for the lake. The current study constructed an updated bathymetric map for 1989 based on fathometer recordings obtained from 12 lake transects (Figure 73). Following convention established by the 1948 map, five foot contours were constructed for the 1989 map.

It is obvious that the depth configuration has changed markedly in the past 41 years. A comparison of the depth distributions for 1948 and 1989 are provided in Figure 74. The 0-5 foot contour in 1948 comprised approximately 40 acres, an area larger than displayed by an other single contour. The second largest contour was the 15-20 foot contour followed by the 5-10 and 10-15 foot contours with approximately 16 acres each. The deepest section of the lake (greater than 20 feet) was less than 15 acres. The 0-5 foot contour still displayed the largest aerial extent in 1989, but 10-15 foot replaced 15-20 foot as the second most important contour. By 1989 the deep water zone (greater than 20 feet) had been reduced to less than 3 acres.

South Mud, IN



South Mud, IN

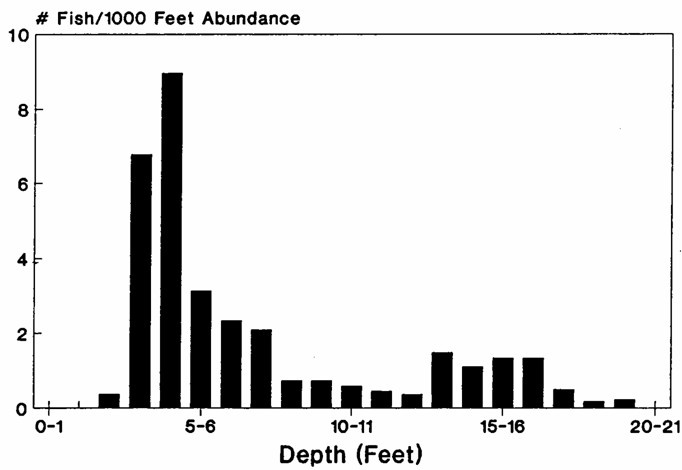


Figure 70. Semi-Quantitative Estimate of Fish in South Mud Lake in July 1989 Expressed as Number of Individuals Per 1000 Feet of Fathometer Transect and Partitioned According to Water Depth.

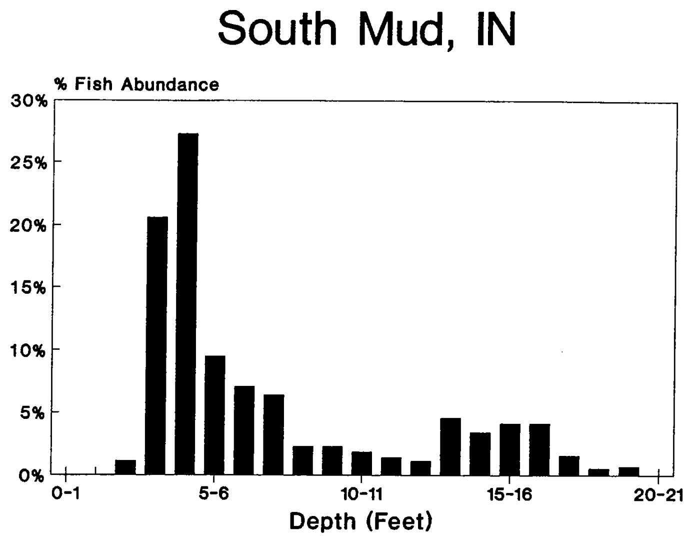


Figure 71. Percentage Distribution of the Fish Community by Depth in South Mud Lake during July 1989 as Estimated from Fathometer Transects.

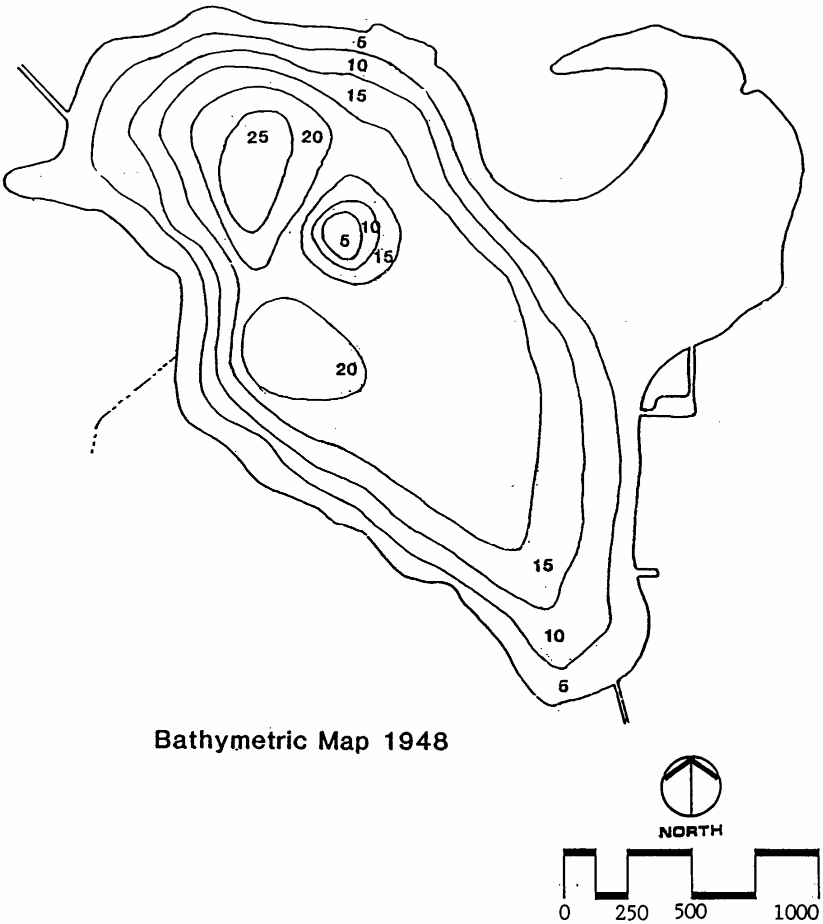


Figure 72. Bathymetric Map of South Mud Lake from 1948.

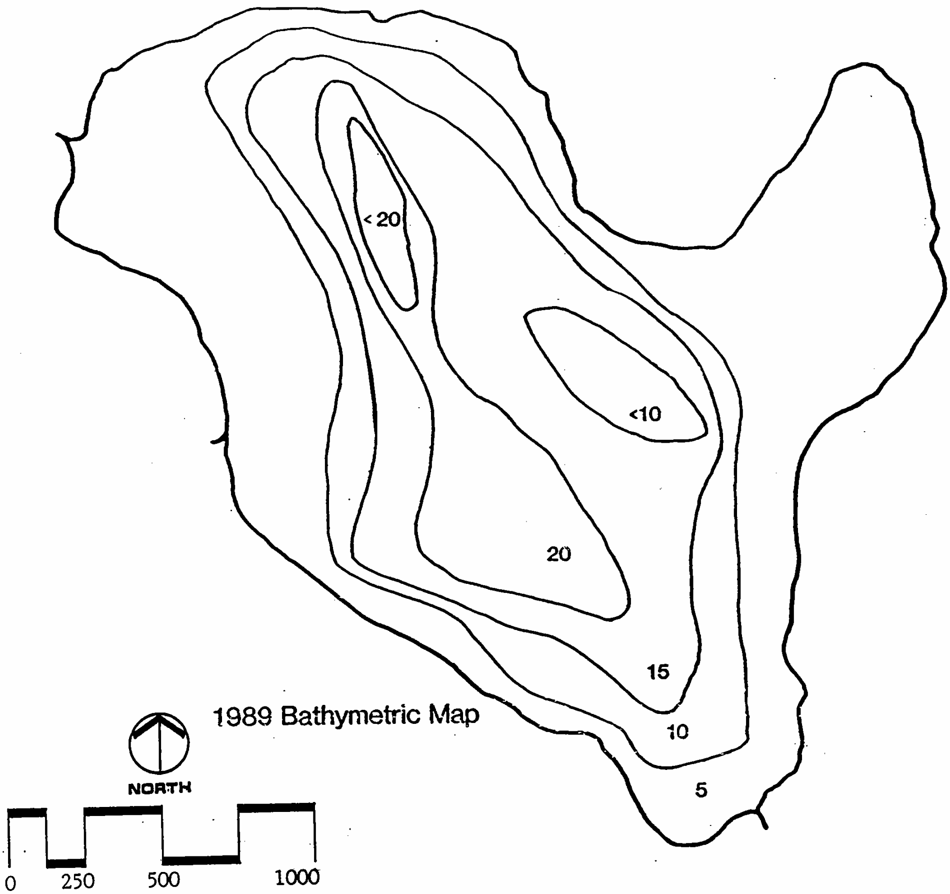


Figure 73. Bathymetric Map of South Mud Lake from 1989.

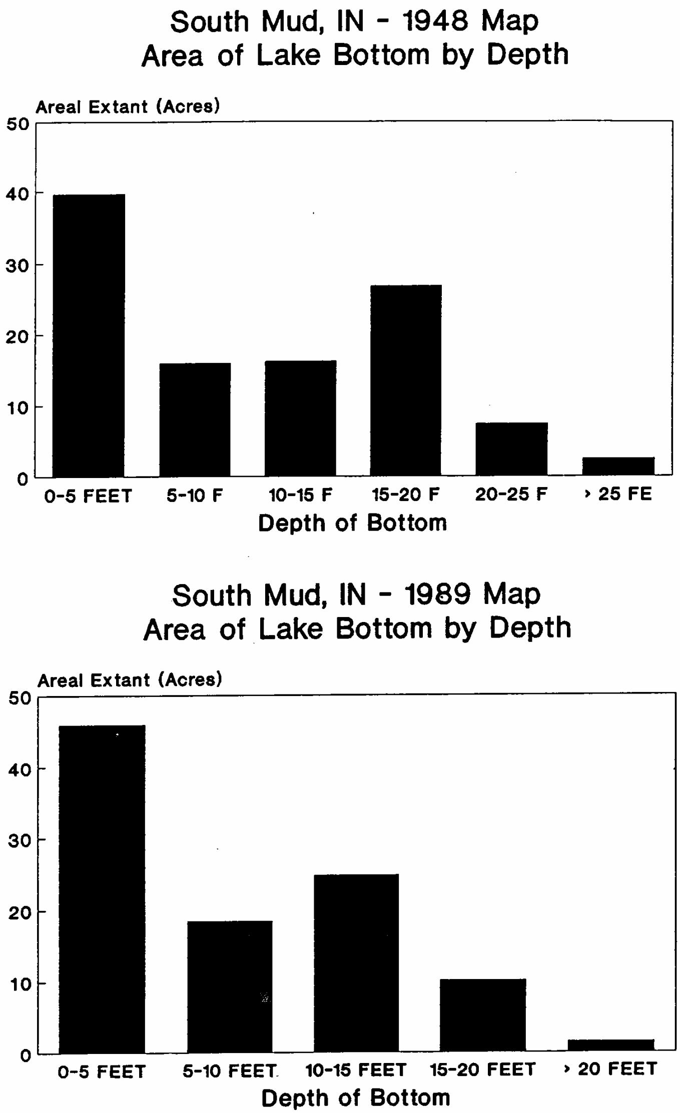


Figure 74. Comparison of the Depth Distribution Within South Mud Lake for 1948 and 1989.

Sedimentation patterns in the past 41 years are extremely clear through comparison of the aerial extent of individual contours for 1948 and 1989 (Figure 75). The aerial extent of the three shallowest depth contours (0-5, 5-10, 10-15 feet) increased since 1948 by 15%, 15%, and 53%, respectively. In addition to the elimination of areas greater than 25 feet, the 15-20 foot and 20-25 foot contours were reduced in aerial extent by 62% and 80%, respectively during the same period.

Infilling was not uniform throughout the South Mud Lake basin but was most pronounced between the inlet of Zanger Ditch and the lake outlet. It is clear that basin sedimentation is strongly controlled by stream input of watershed erosion products. The sediment loading from the Rannels and C. Brown Ditches appears to be minor importance compared with that of the Zanger Ditch. It is suggested that the sedimentation contributed from the Zanger Ditch will increase further as a direct result of the recent dredging activity to clean the system. The two other contributors to lake infilling, motor boating and shoreline erosion, are not considered to be important contributors to the observed pattern of sedimentation in South Mud Lake.

Sediment Studies

Sediment Contaminants

A piston coring device equipped with a clear plexiglass tube was used to collect a one-meter core from the deepest section of the north basin of South Mud Lake. This technique permitted examination of the core to insure that the sediment-water interface was not disturbed during the coring operation. The core was extruded in 10 cm sections and placed in labelled plastic bags. All core material was kept cool at 4^{o} C until analyzed. Prior to analysis, the 0-10 cm interval was thoroughly mixed and extracted for metal and organic contaminant analyses. This upper most interval provided sufficient material for our investigation.

The metals and organics data are presented in Table 20. A total of 20 metals were analyzed with the highest concentrations being exhibited by calcium, iron, aluminum, magnesium, and manganese. All metal values were considered within the range expected for the glaciated portion of Indiana. In addition, 24 possible organic contaminants were analyzed. As with the metals, concentrations were not considered to pose any environmental threat. Given that none of the 44 analyzed parameters were considered to exceed permissible levels, it is most probable that the sediments

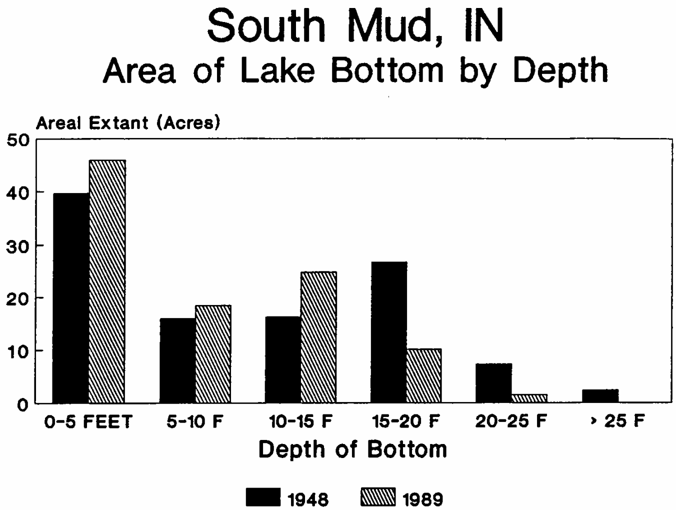


Figure 75. Comparison of the Aerial Extent of Individual Depth Contours Within South Mud Lake for 1948 versus 1989.

Table 20. Concentrations of Metals and Organic Chemical Contaminants in Surface Sediments of South Mud Lake.

METALS	ug/g dry wgt	ORGANICS	ug/g dry wgt
% Solids	13.6	2,4,5-T	<0.7
Ag	<5	2,4,5-TP (Silvex)	<0.7
Al	9890	2,4-D	<0.7
Ba	225	2,4-DB	<0.7
Be	<2	B-BHC	<0.01
B	15	D-BHC	<0.01
Cd	2	Methoxychlor	<0.2
Ca	257000	Toxaphene	<0.2
Cr	16	4,4´-DDD	<0.02
Cu	25	4,4´-DDE	<0.02
Fe	9800	4,4´-DDT	<0.02
Pb	15	A-BHC	<0.01
Mg	6960	Aldrin	<0.01
Mn	889	Chlordane	<0.02
Mo	10	Dieldrin	<0.01
Na	147	Endosulfan I	<0.02
Ni	12	Endosulfan II	<0.01
Sr	267	Endosulfan sulfate	<0.05
Ti	117	Endrin aldehyde	<0.02
V	42	Endrin	<0.01
Zn	54	G-BHC (Lindane)	<0.01
		Heptachlor epoxide	<0.05
		Heptachlor	<0.01
		PCB´s	<0.05

throughout the remainder of South Mud Lake are free from serious chemical contamination as well.

Sediment Core Profiles

Sediment cores were collected at the deepest location of South Mud Lake (Figure 76) by means of the same piston coring device described in the previous section of this report. As always, the plexiglass tubing permitted inspection of the core to insure that the sediment-water interface was left undisturbed during the coring operation. Only the core which we felt absolutely met this requirement was saved for analysis. The total core length collected from the lake was 128 cm.

The core was extruded within two hours of collection and sectioned at 1 cm intervals with each sample being placed in a plastic bag for storage. All samples were then kept at 4^{o} C until analyzed. In addition to wet weight for select core levels, organic content was calculated as the difference in weight between the wet weight and that after drying at 100^{o} C for 24 hrs. Inorganic content was calculated from the weight difference of the sample dried at 100^{o} C for 24 hrs and ashed at 500^{o} C for one hour. Phosphorus was determined by the standard ascorbic acid colorimetric method using filtrate collected from an HCl digestion of the sediment sample.

Water content of the South Mud Lake core decreased from greater than 80% for levels deeper than 120 cm to 74-76% for levels less than 120 cm (Figure 77). The notable exception to this trend was the uppermost 6 cm where water content again rose to greater than 80%. Sediment organic content (Figure 78) dropped sharply from 35-40% for core levels greater than 120 cm deep to less than 20% for levels above 90 cm. Organic content remained relatively steady up to 40 cm above which it continued to decline to less than 15% by 18 cm where it remained unchanged to the surface.

The profile for inorganic content was the mirror image of the organic profile (Figure 78). Following a percentage rise from 62% at 127 cm to 83% at 80 cm, inorganic content remained relatively steady until the uppermost 18 cm where values increased to greater than 85%. The sediments of South Mud Lake were much more inorganic than those of any other natural lake of northern Indiana that we have investigated. Such extremely high inorganic content is characteristic of reservoirs not natural lakes. Eutrophic natural lakes such as South Mud normally have greater than 80-90% organic matter.

Coupled with evidence from the 1948-1989 bathymetric map comparison, the highly inorganic nature of the sediments

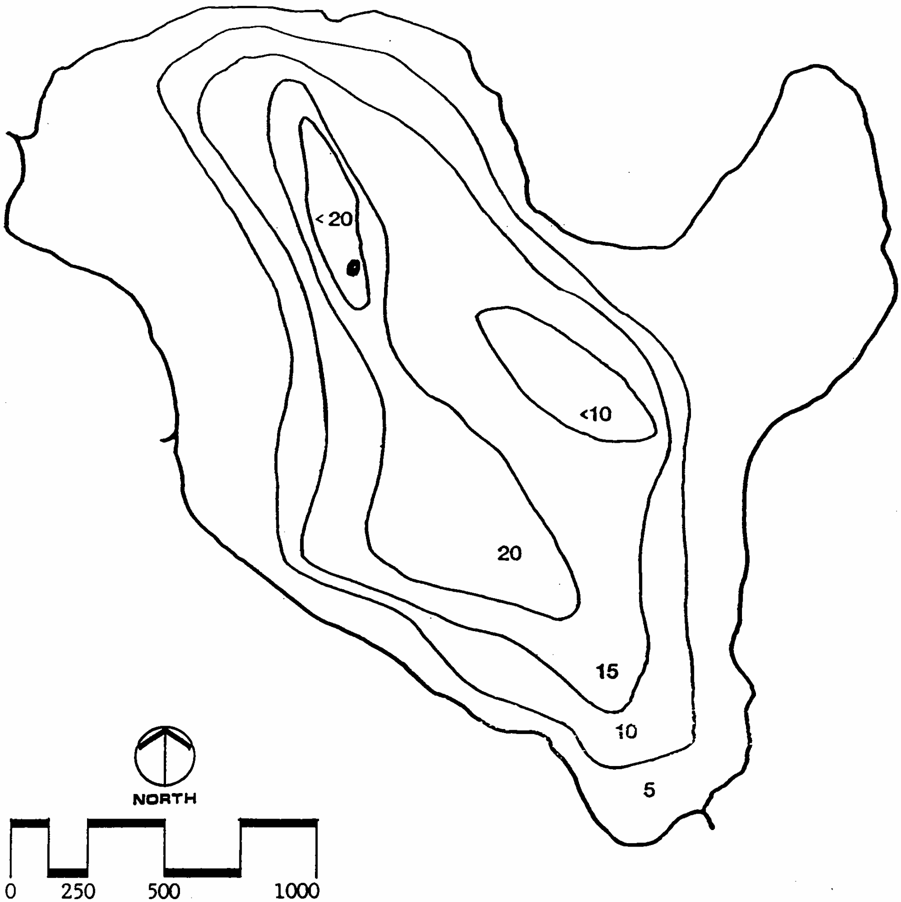


Figure 76. Site of Sediment Core Collection in South Mud Lake During 1989.

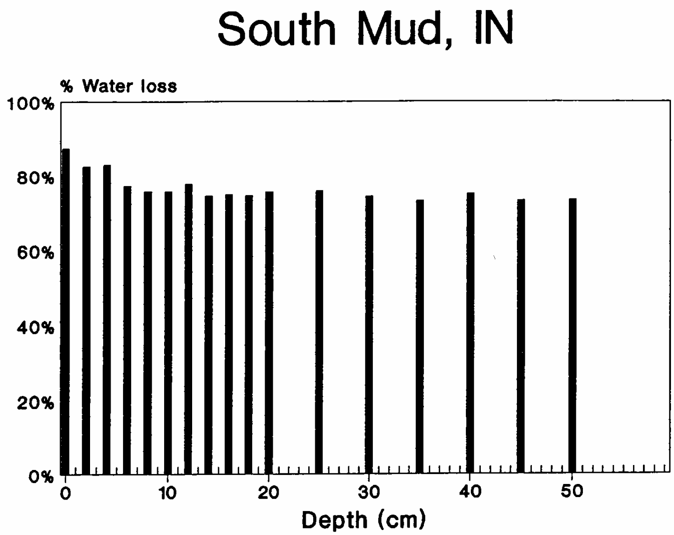
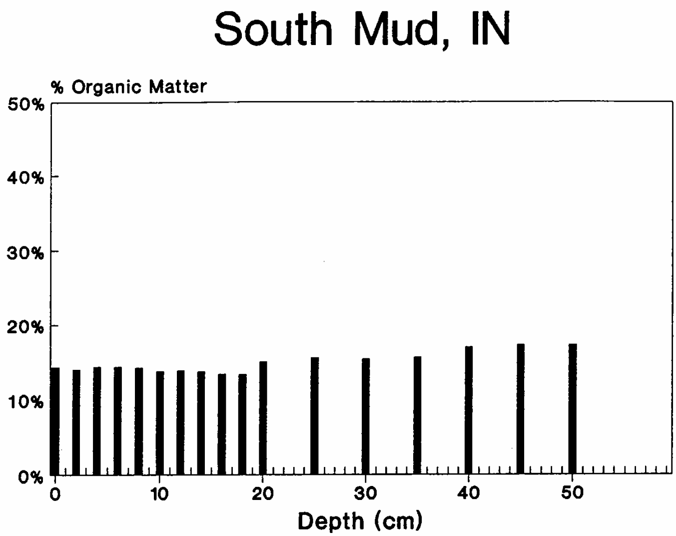


Figure 77. Profile of Percent Water in the Sediment Core From South Mud Lake.



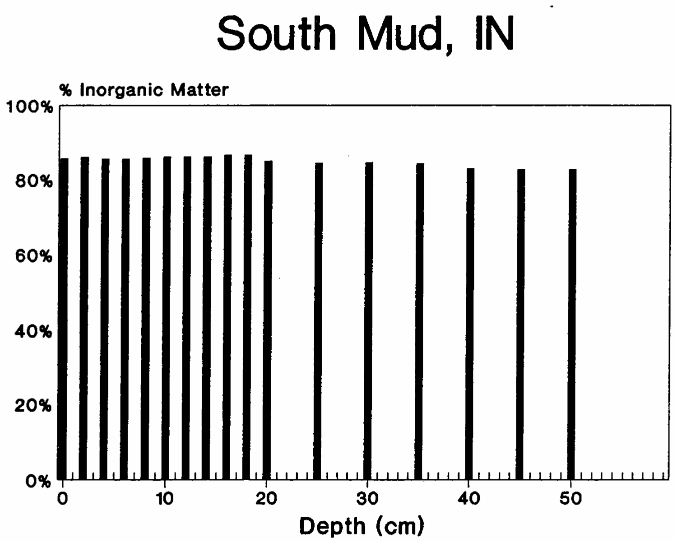


Figure 78. Profiles of Percent Organic and Inorganic Matter in the Sediment Core From South Mud Lake.

suggests an extremely high delivery and subsequent deposition rate of watershed derived inorganic sediment by ditches, especially Zanger Ditch. The fact that the color of the upper 35 cm of the core changed to a light brown color characteristic of silt suggests that the delivery rate of sediment from the watershed has accelerated in recent years. It is normal for eutrophic Indiana lakes to deposit in excess of one meter of sediment in one hundred years (Crisman 1987). Bathymetric map comparisons coupled with core studies clearly demonstrated that silt delivery to the lake has increased markedly since at least 1948, and most likely 1970. Given the clarity of this stratigraphic signal, we have not had to resort to 210-Pb dating, a parameter for which no charge was included in this investigation.

It is conventional to express total phosphorus concentrations as a function of the total dry weight of sediment at a particular depth in the core (Figure 79). In this way, deviations in the total phosphorus to sediment dry weight ratio can be used to delineate periods of past phosphorus enrichment in the lake. The ratio decreased from maximal values greater than 120 cm deep to approximately 1.3 at a depth of 110 cm. Ratio values decreased steadily from 60 cm to 30 cm above which they increased to the surface. Such ratio trends must be interpreted cautiously in lakes such as South Mud which display pronounced stratigraphic changes in the percentage contribution of inorganic matter.

It is clear from Figure 80 that with the exception of the lowermost core levels, the profile of total phosphorus content roughly parallels that of percent organic matter. These data suggest that phosphorus is entering South Mud Lake in a form that is easily utilized for algal and macrophyte growth.

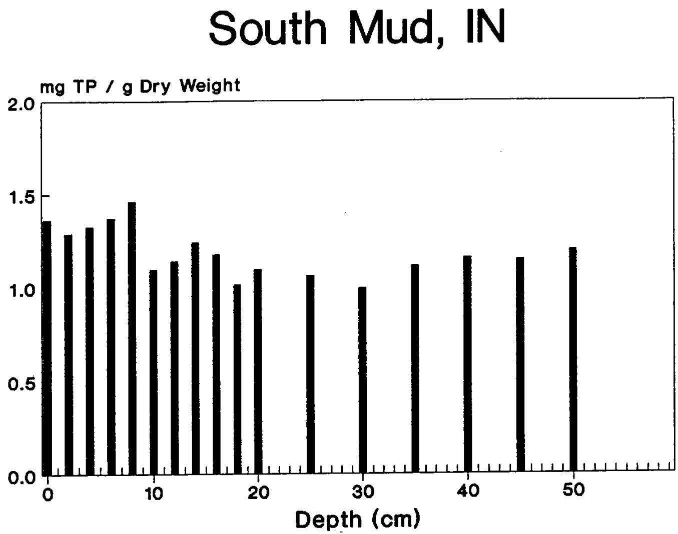


Figure 79. Profile of Total Phosphorus Concentrations in the Sediment Core From South Mud Lake.

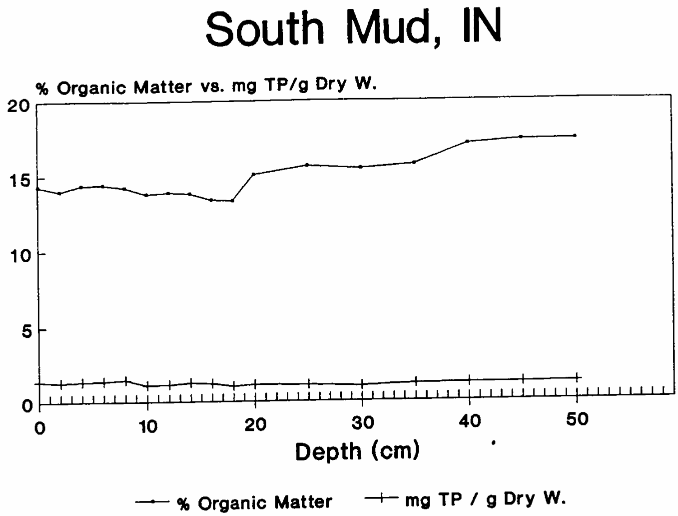


Figure 80. Comparison of Profiles of Organic Matter Percent and Total Phosphorus/Gram Sediment Dry Weight for the Sediment Core From South Mud Lake.

The Watershed 3.

The Watershed

The approach of this part of the study is to specifically address the effect of the off-site watershed on the Lakes. After preliminary investigation, the method was to target the area(s) of highest concern. Basically, our study had to start from the beginning to discover how this watershed was contributing to challenges in this lake system. The concerns to be identified in the watershed were as follows:

a. Nutrient contribution to the Lake(s);
b. What are the probable sources;
c. How much sediment is coming into the Lake(s);
d. How can sediment be reduced;
e. What are the intrinsic values of the watershed, and
f. How can the sources of sediment/nutrients be reduced from affecting the lake(s)?

This feasibility study included the use of the following resources:

a. Reconnaissance of the entire watershed by site visits on several occasions;

b. Walking tours of some private property areas that could not be properly observed from public areas;

c. Aerial photographs (County Surveyor);

d. Aerial photographs (USDA - Soil Conservation Service, 1971 and 1978);

e. Aerial color infrared photographs (NAPP, 1981);

f. United States Geological Survey (USGS) map, Macy Quadrangle;

g. United States Fish and Wildlife Service, National Wetland Inventory map, Macy Quadrangle;

h. USDA - SCS Soil Surveys of Fulton and Miami Counties Indiana, issued 1987 and 1979;

i. Fulton and Miami County records: Auditor, Surveyor, Treasurer, etc:,

j. Various meetings and/or telephone conversations with State & County agencies, local property owners and;

k. Engineering reconnaissance by ESI to determine suitability of potential target sites.

The main purpose of this investigation was to target the area(s) which would be the highest priority(ies) for land treatment systems for trapping nutrients and sediments in the watershed. Possible solutions may consist of settling basins, constructed wetlands, sediment traps, ponds, shallow water habitat areas, or variations in agricultural and non-agricultural land-use practices, etc. These terms are descriptive of similar broad-scale land treatment concepts that would reduce nutrient and sediment loading to the Nyona/South Mud lake system. Other upland agricultural practices such as terracing, grassed waterways, conservation tillage, and animal waste disposal are all vital methods to improving the water quality of the lakes (Appendix C and D). These practices, however, are largely beyond the direct control of the Lake Association. Local SCS and ASCS offices have been appraised of the areas felt to be contributing excessive amounts of sediment and nutrients or that would otherwise benefit from programs beyond the scope of the Lake Enhancement study. The goal of this feasibility study is to focus on the site(s) of greatest potential; to most benefit the lake system in the shortest time; and to attempt to identify the process to create this system and its costs. The final considerations that would evaluate the feasibility and/or priority of such constructed projects would then be up to the Lake Association leadership. Discussions with Mr. Dan Rosswurm at the Fulton County Soil Conservation Service office indicated the awareness of problems with soils and agricultural practices above the lake(s). The SCS has pledged to help the Lake Association in any way possible including technical support, and initiating discussions with owners of properties which are contributing intolerable amounts of sediment, nutrient, and animal waste runoff. The SCS would be important support on the larger constructed solutions, and could be of prime responsibility to encourage and/or design the other <u>upland practices</u> and structures. Field reconnaissance by **Earth Source Inc.** in late winter 1989 noted a great deal of conservation tillage and very little fall plowed land in the watershed. This was very encouraging, especially in the areas east of the lakes.

Watershed impressions by visual survey

The purpose of this section is to express in narrative form the observations and general visual impressions that were made during site tours of the watersheds. The intent is to provide a perspective that may be fresh and to stimulate residents to make their own continuing observations (Figure 81).

Nyona Lake and its watershed

1. Nyona Lake proper is a very pleasant landscape of well-kept homes. A comfortable sense of history and evolution of development blends into the rolling hills and oaktreed slopes. It is unique that a road bridges near the center of the Lake. In the northern basin, it is possible to look across to the east shore that is almost free of development much as it would have appeared a couple centuries ago. The south basin is nearly completely ringed with homes and also includes the Public Access. It is easy to realize why people are comfortable here and have so much concern about the condition of the lake and why it is changing.

2. East of the lake (south of the road) is a large area of sloping land that appears to have been cleared recently. Sediments are very likely washing directly into the Whitmore Ditch and the roadside.

3. The major inlet to Nyona Lake in the north basin (Whitmore Ditch) is a deep and wide man-made channel bordered by a mobile home and camper/vehicle park. How did this look before channelization? What could or should be done now with this area?

4. Continuing east, we encounter an old gas station, and then, across U.S. 31 in itself is a major traverse of the Nyona watershed, which may also be a contributor of pollutants and perhaps hazardous waste.

5. The upland east of U.S. 31 in Miami County is flat to gently rolling. Drainage patterns are not obvious. The open ditches in the upland area (Clemans-Smith, Whitmore, and Fenters) are deep and connect broad flat plains that may have an occasions short steep slope that defines the drainageway.

6. Upland depressions, potholes, land wetlands are scarce. Did they ever exist in this landscape?

7. The Fenters Ditch was recently extended in Section 24. It didn't appear to have resulted in out-of-the-ordinary new contribution to water quality problems.

8. During the late winter tour, it was noted that <u>very</u> little land in this area had been fall worked. Often, fields had apparently been no-tilled or in a minimum-tillage program.

9. Only several farms still had visible animal operations. One site has a highly-eroded hillside hoglot near the Whitmore Ditch. (This site is discussed elsewhere for treatment.) A second area along Whitmore Ditch and east of 400 West includes a farm lot and pasture area. Maybe an opportunity to improve waste handling and pasturing programs here? On Old U.S. 31 is a well-kept farm with cattle and sheep.

10. The Town of Macy apparently does <u>not</u> contribute to this watershed.

11. Returning to the watershed west of Nyona Lake, we find a wetland area that is mostly being used for pasture. Very little area sheds into this site and has no apparent surface flow connection to Nyona Lake. To the lakeside, it is apparent that many homes are constructed near lake level, probably on organic and poorly drained to saturated soils.

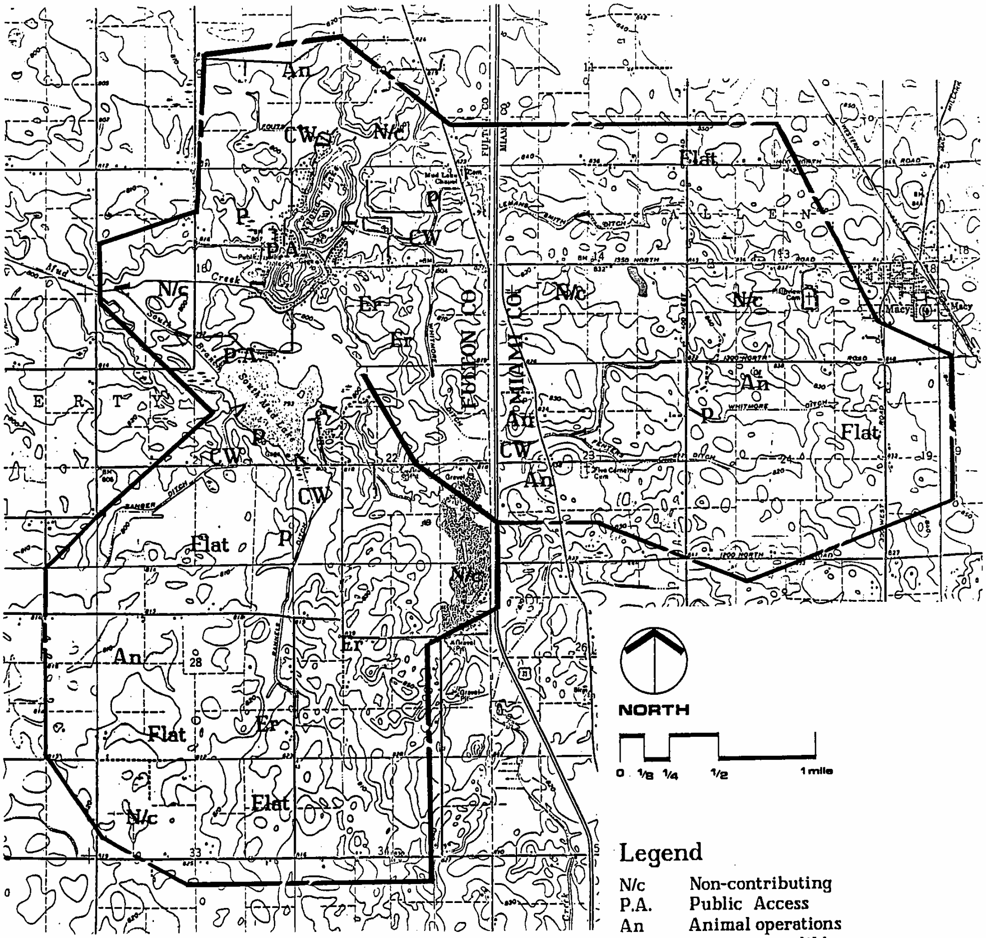
12. Looking at Fouts Ditch, we find a small shallow flow from cropland. The cropland includes some "bottomland" with very productive soils. Some slopes occur, but don't appear to be seriously contributing to the ditch. Again, a small area, but probably contributing some fertility to the Lake. Also nearby is a dairy farmstead which appears to be remote from direct contribution to the ditch and therefore to the Lake.

13. To the northeast of the lake is another rolling area, some of which is in row crops. This area appears to be well buffered from the Lake, however, this could be a problem area if drainage was connected to the Lake in the future. A likely problem area occurs along the Clemens-Smith Ditch which a heavily pastured into the Ditch. Waste handling may also be a concern nearby, aside from direct input of animal waste and sediment disturbance to this ditch.

14. With some difficulty, we visually inspected the outlet control structure. It is apparent that access to the structure is across private lots and lands. Although some fertility is apparent in the lake channel above the control structure, the water appears clear. The lake is serving well as a **<u>sediment and nutrient sink!</u>**

NYONA, SOUTH MUD LAKES WATERSHED TOUR

(Figure 81)



Legend

N/c	Non-contributing
P.A.	Public Access
An	Animal operations
Er	Appears erodible
Flat	Relatively flat land
CW	Possible constructed option site
⊿	Flow direction
P	Pasture

South Mud Lake and its watershed

1. South Mud Lake proper has a very different appearance from Nyona Lake. Almost all of its shoreline is cleared of trees and bordered by flat marshy areas. The wetland in the northeast quarter of the lake appears very outstanding as a habitat. Although probably extremely important to the water quality health of the Lake, very little watershed enters the lake through this marsh.

2. On the lake's north shore are some residences and the Public Access site. The Lake outlets nearby to the South Branch of Mud Creek.

3. The west side of the lake has a very small contributing watershed.

4. Coming to the southwest quarter of the lake, we encounter the Zanger Ditch. Recently "cleaned", the ditch bank is eroding severely and the ungraded spoil bank (at that time) was piled next to the south bank of the ditch, also washing back into the ditch. Only viewed from the road, it was unknown (only feared) how this project may have affected the Lake. Had sediment traps been installed? Were the traps maintained? Was it ditched entirely to the Lake? The upland part of this watershed did not appear to have significant contributing factors such as slopes and highly erodible soils. So, it is apparent that if there are problems from this project that it is substantially from the operation itself until the ditchbank and spoil bank stabilizes.

5. A majority of the south shore is pasture on both sides of the road. The lake shore is also pastured and cattle were observed wading out into the Lake. (Can't get more direct inputs than this...) Shoreline grazing also breaks down the filtering edge of plants and re-suspends sediments.

6. The upland portion of the Zanger shed is relatively flat and in high production.

7. At the southeast corner of South Mud Lake, we encounter the Rannels Ditch inflow. A very nice marsh filters the last several hundred yards of flow before entering the Lake. The water in the minimal flow appears very clear.

8. Upon traveling to the upland portion of the Rannels watershed, we are concerned by the high amount of slope and apparently erodible soils. This is also a relatively large sub-watershed to South Mud. The concerns are that the excellent filtering marsh may be destroyed by ditching, or damaged by an overloading of sediments and nutrients from the rolling watershed above.

The opportunity observed is that immediately above the existing marsh, an expanded marsh or constructed wetland could be created thereby protecting the marsh and giving further trapping of nutrients and sediments.

9. On the east side of the lake is a small shallow drain known as the C. Brown Ditch. The last four-tenths of a mile is very flat in profile. Flowing near lake level, the `ditch' is currently mostly grass and tree covered. The water appears very clear. It seems that ditching occurred many years ago as evidenced by the spoil banks. As the ditch functions now, it is probably doing an excellent filtering job.

10. In viewing the upland portion of the C. Brown Ditch, quite a lot of slope occurs. Also, a gravel pit is operating. The pit does not appear to be directly connected to the ditch by surface flow, therefore sediment from operations does not reach the ditch. (Good!)

11. The only other residential area on South Mud Lake is off the southeast shore. These homes are mostly on upland soils, however their wastewater systems may not be.

Photospectroscopy

Aerial photography is quickly becoming an intricate tool for use in many topographic and natural resource applications.

In doing a land use study using aerial photography, several items must first be considered to provide the most accurate detailed information possible in obtaining the desired data.

First, and probably most important in doing a study of primarily agricultural usage, the "type" of photograph used is important. For the most part, two "types" of photographs exist: 1) those taken in the visible spectrum, and 2) those taken in ultraviolet or infrared spectrum of light. Since all living organisms emit energy in wavelengths of light, and since our study is based primarily in an agricultural and watershed area, color infrared photography was used.

This type of photography delineates plants through size, density, and respiration, by photographing specific intensities of red hues. Conversely, fallow lands, lakes and wetlands appear as grey or black areas on the photo.

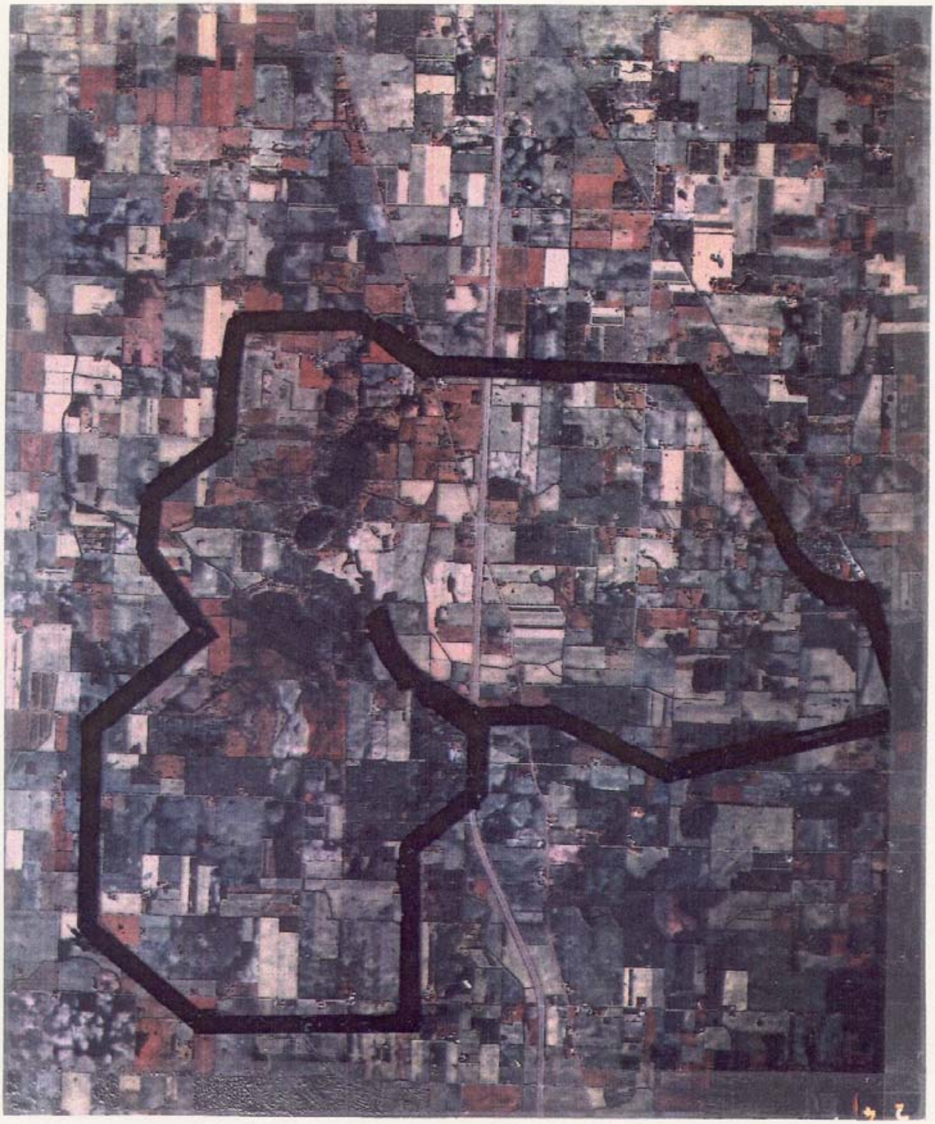
Second, the date in which the photographs were taken is an important consideration in the determination of the results and comparison to current trends.

Month and day play a factor in the interpretation of the types of vegetation and wetlands described. An extreme example of this would be trying to distinguish agricultural usage on a photo taken in July compared to the same photo taken in December. The day is also a factor because of previous weather conditions. The photographs used for this study were taken on the November 12, 1981 fly-over at a scale of 1:60000 (Figure 82).

In doing the study of Nyona-South Mud, the entire watershed was laid out on the photographs using a transparency, and then divided into respective sub-watersheds. The size of an overlay grid (1 acre) was then calculated, drawn, and then placed over the photos. From there, each sub-watershed was divided into the following land use categories:

Forested (woodlots)
Active agriculture (row crop)
Grasslands (or low agricultural)
Fallow
Wetlands
Residential

An additional division was made specifically for Nyona-South Mud Lakes.



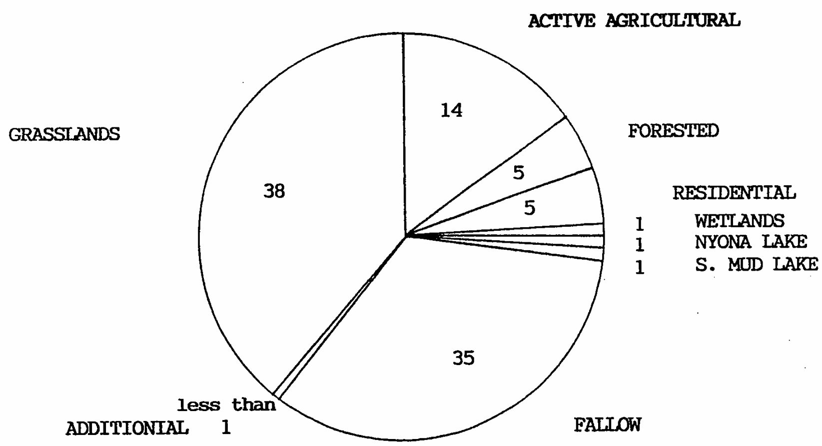
(Figure 82)
1981, color infrared, aerial photograph of the Nyona-South Mud watershed. Overlapping photos were viewed using a stereo scope to determine land-use.

Results of the survey are shown in Table 21, and each area is broken down into a percent of the entire watershed.

Additional graphical representation of each land use category is shown in Figure 83. Those results given are results as of 1981 information.

Climatological data for Indiana during October and November of 1981 indicates that the average monthly precipitation for this time period was .57 and 1.49 inches below normal respectively. Interpretation of this data lends to the accuracy of the wetland data if not slightly underestimating it.

Due to the time frame of the photographs, classification of the agricultural subdivisions may be skewed to one class or another, but overall determination of agricultural usage is accurate.



NYONA, S.MUD LAKES
LAND USE DISTRIBUTION BY PERCENT

(Figure 83)

WATERSHED CHARACTERISTICS	
Drainage Area (acres)	8742
Active Agriculture	1230 (14%)
Fallow	3019 (35%)*
Forest	467 (5%)
Grassland	3307 (38%)**
Lake: Nyona	114 (1%)
South Mud	120 (1%)
Residential	390 (5%)
Wetlands	81 (1%)
HEL	17 (<1%)
Potential HEL	1936 (22%)
Basin Slope (m/km):	
Nyona	4.61
South Mud	8.51
Precipitation (in/yr):	
Mean	37.5
Standard Deviation	14.0

Table 21. **Characteristics of the Nyona/South Mud watershed, October/November 1981.**

* Includes agricultural land with harvested row crop.
** Includes wheat residue, harvested in July 1981.

Topography

The watershed of Nyona/South Mud is best described as a morainal topography. The highest point in the Nyona/South Mud watershed is 860 feet above sea level and the lowest point is 762 feet above sea level. The average elevation in the Nyona/South Mud watershed is approximately 825 feet.

Relief throughout the watershed is characterized by gently sloping to level. Basin gradients in the watershed range from 4.61 m/km in the Nyona sub-watershed, to an extreme of 8.51 m/km in the South Mud sub-watershed. Slopes range from 0 to 18 percent.

Severe slopes

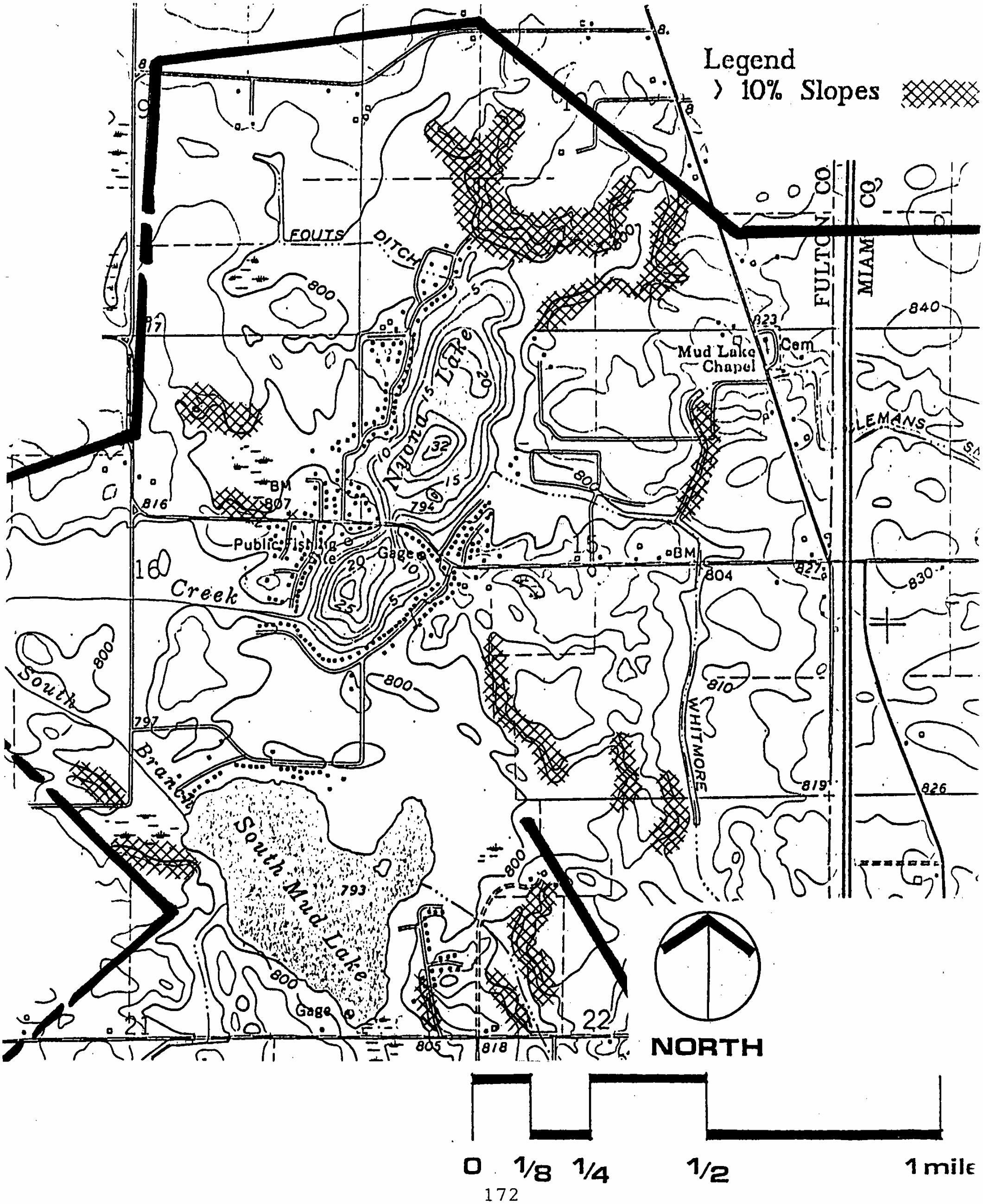
The length and steepness of slopes are major factors in assessing the probable erosion risks of an area. On steep or long slopes, runoff water accumulates in channels where increased flows produce greater erosive forces. Level or flat lands produce shallow overland flows over a larger area, this decreases the erosive forces of runoff.

The intent of this study-map is to further illustrate the fabric of the land forms in the watershed. This study provides further evidence where the study emphasis should be. Some of the slopes indicated are in an area identified as having a "low contribution" of sediments. This graphic also substantially matches the worst conditions of Highly Erodible Lands.

In general, areas mapped as having severe slopes should not be in agricultural crop production or should be in a conservation tillage program. Some of these sloped areas are also too steep for development without special care, if at all (Figure 84).

NYONA, SOUTH MUD LAKES
SLOPE STUDY

(Figure 84)



Geology

The first intrinsic value of any watershed rests in an understanding of the underlying geology, the base from which a watershed is built. The Nyona/South Mud watershed is underlain by bedrock of the Wabash Formation. The Wabash Formation consists of limestone, dolomite and argillaceous dolomite laid down in the Middle Silurian Period of the Paleozoic Era (421 to 428 million years ago).

The Wabash Formation is covered by over 200 feet of partially lithophied to unconsolidated glacial deposits. The most recent glaciation occurred some 12,000 years ago during the Wisconsinan Advance. The Nyona/South Mud watershed is comprised of sediments deposited from the Huron-Saginaw Lobe of the Wisconsinan Ice Sheet. This material is dominated by an outwash association of sand and gravel fan deposits. More complex till of the area consists of stratified drift in chaotic form. This makes up the clay-loam to silt-loam till of the Wedron formation. For further discussion on surface geology, see soils.

Soils

The soils of the Nyona/South Mud watershed are grouped in the Wawasee-Crosier-Barry Association (Figure 85) by the Fulton County Soil Survey. This association is further characterized by gently sloping to strongly sloping areas along drainageways and small knolls and ridges. The association is approximately 40% Wawasee and similar highly erodible lands (HEL), 25% Crosier soils, 20% Barry/Brookston soils and 15% other inclusion soils. The well drained, gently sloping to strongly sloping Wawasee soils are on till plains, knolls, and ridges and on side slopes around deep potholes and along drainageways. Typically, they have a surface layer of dark brown fine sandy loam and a subsoil of dark yellowish brown loam and sandy clay loam.

The somewhat poorly drained, nearly level Crosier soils are in broad, slightly convex areas and on slight rises. Typically, they have a surface layer of dark grayish brown loam and a subsoil of grayish brown and dark brown, mottled clay loam and loam.

The poorly drained, nearly level Barry soils are in depressions and along poorly defined drainageways. Typically, they have a surface layer of black loam and a subsoil of dark gray and gray, mottled sandy clay loam and fine sandy loam.

The minor soils in this association are the well drained, sandy Metea soils on knolls and on side slopes along drainageways. (source: Fulton county soil survey)

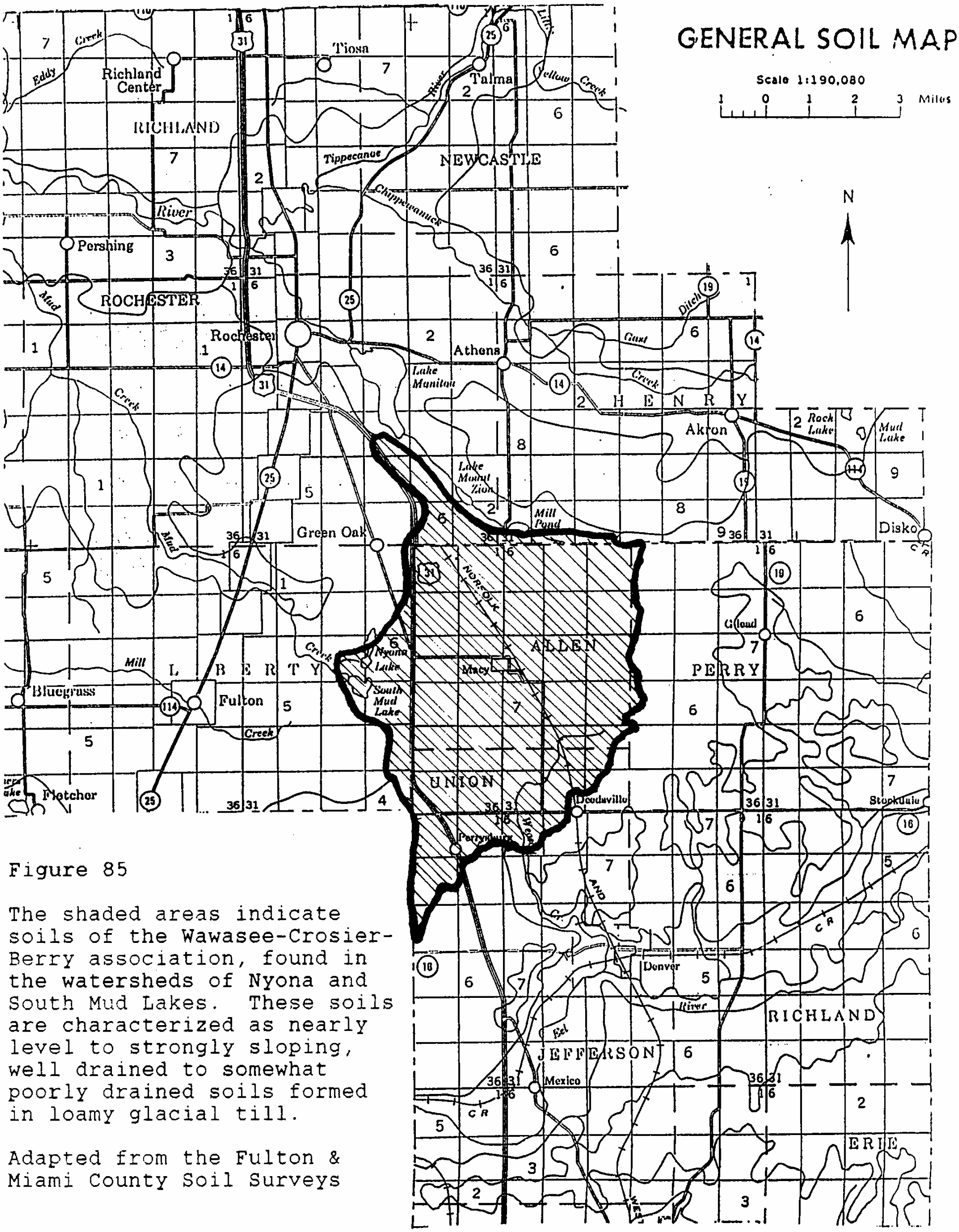


Figure 85

The shaded areas indicate soils of the Wawasee-Crosier-Berry association, found in the watersheds of Nyona and South Mud Lakes. These soils are characterized as nearly level to strongly sloping, well drained to somewhat poorly drained soils formed in loamy glacial till.

Adapted from the Fulton & Miami County Soil Surveys

Highly Erodible Land (HEL)

The purpose of identifying areas containing HEL is to display the origin of potential sediment sources so that the study may target areas of general concern. Using the Soil Survey of Fulton and Miami counties by the USDA-SCS issued in 1987 and 1979 respectively, and data provided by the local SWCD and SCS offices, soils of the HEL designation were mapped as shown in Figure 86.

The following highly erodible soils occur within the Nyona/South Mud watershed and have been highlighted in Table 22.

Chelsea fine sand, 2 to 6% slopes **
Fox clay loam, 8 to 15% slopes *
Kosciusko-Ormas complex, 2 to 6% slopes **
Kosciusko-Ormas complex, 6 to 12% slopes **
Metea loamy sand, 6 to 12% slopes **
Pits, gravel **
Plainfield sand, 6 to 12% slopes **
Riddles fine sandy loam, 6 to 12% slopes **
Wawasee fine sandy loam, 2 to 6% slopes **
Wawasee fine sandy loam, 6 to 12% slopes **
Wawasee sandy loam, 2 to 6% slopes **
Wawasee sandy loam, 6 to 12% slopes **
Wawasee loam, 6 to 12% slopes **
Wawasee loam, 12 to 18% slopes **

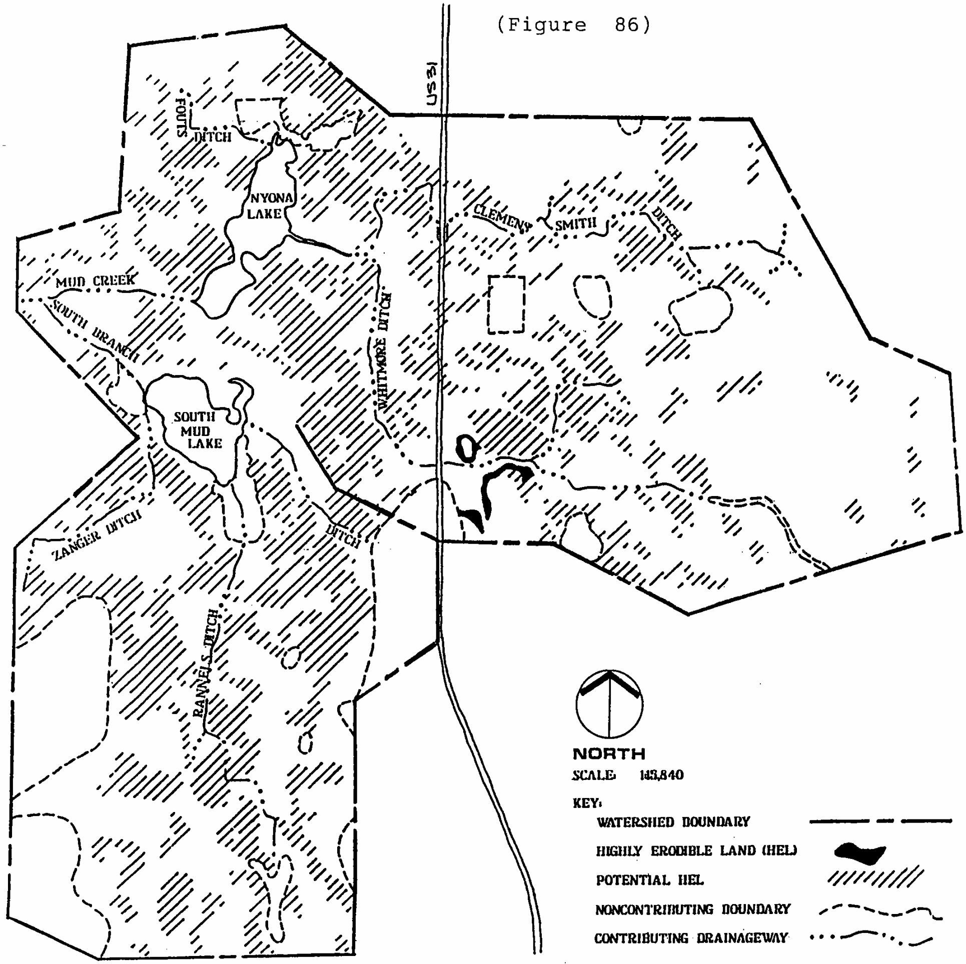
*	Highly erodible land
**	Potentially highly erodible land

Table 22. **HEL and Potential HEL soils of the Nyona South Mud watershed.**

HEL or potential HEL was found to comprise 31.0% (apx 2681 ac) of the Nyona/South Mud watershed. The study area was then further divided to determine contributing and non-contributing HEL. Approximately 99% (2633 ac) of the total HEL are considered to be directly contributing to Nyona and South Mud lakes. Target sediment sources were located using the HEL map and will be discussed further in the recommendations and conclusions section of this report. The Nyona/South Mud watershed is somewhat unique in that very few upland depressions exist. Nearly all of the area is contributing due to this naturally contributing surface topography. This also creates challenges for targeting locations of suitable areas for nutrient and sediment removal.

NYONA-SOUTH MUD LAKES
WATERSHED STUDY
HIGHLY ERODIBLE LAND (HEL)
FULTON-MIAMI COUNTIES
INDIANA

(Figure 86)



Erosion: Causes and Prevention

Erosion of soil is primarily caused by the force of rain drops striking the ground and secondly by the force of water flowing in rills or channels. As rain falls on unprotected ground it breaks small particles of soil free. These soil particles are then carried away by sheets of water. Naturally, as the intensity of rainfall increases, velocity and volume (flow) of runoff increases, thus potential soil erosion increases.

Types of soil erosion probable or noted in the Nyona/South Mud watershed:

1. Raindrop erosion due to the impact of rain on unprotected land.

2. Sheet erosion or overland flow causes exposed soil to be suspended by the action of the flowing water, this is common on sloping to nearly level unprotected land.

3. Rill and gully erosion is the result of concentrations of runoff water in riverlates. Rill erosion may cut several inches into the topsoil, gully erosion resulting from unmaintained rills or drainages may cut several feet into the surface.

4. Streambank and channel erosion causes a scouring of stream bottom and undercutting of stream banks.

5. Wind erosion, similar to sheet erosion is caused by the turbulent force of the wind over unprotected land.

The erosion potential of a given area may be determined by four criteria: 1) soils; 2) surface cover; 3) topography; and 4) climate.

An understanding of soils, and the factors involved in making soil more susceptible to erosion, include: soil texture, soil structure, soil content of clay or organic material and soil permeability. Maintaining adequate surface cover either in the form of vegetative cover or crop residue are important factors in reducing soil loss.

The realization is that soil is a valuable resource, and particles are difficult and expensive to recover once erosion has begun.

Prevention is easier than correction!

Useful concepts in erosion prevention and control:

a. Maintain natural vegetative cover wherever possible.

b. Protect sloping areas. Row cropping should be done perpendicular to slope. Vegetation is difficult to establish and maintain of eroded slopes.

c. Divert runoff from severely sloping areas.

d. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.

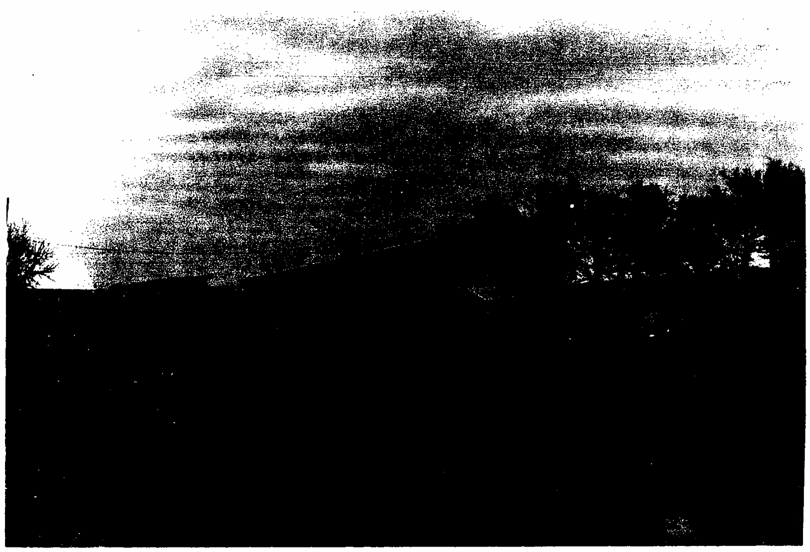
e. Stabilize drainage areas immediately following any construction or "maintenance".

f. Leave natural buffer areas along streams and ditches.

g. Stabilize stream bank or ditch escarpments.

h. Utilize sediment ponds below feed lots and "open" sloping lands.

i. Construct and maintain sediment control structures **prior** to construction of any lake or waterfront development.



Septic System Study

The goal of this study was to estimate potential septic system inefficiencies. Ineffective septic systems have been documented to contribute excessive amounts of nutrients to a lake and likely share in the cause of a poor overall water quality rating. Using data collected on saturated soils (Table 23) and comparing it with building records from 1960 and 1980, trends were established indicating septic systems that were potentially located in saturated soils (Fig 87).

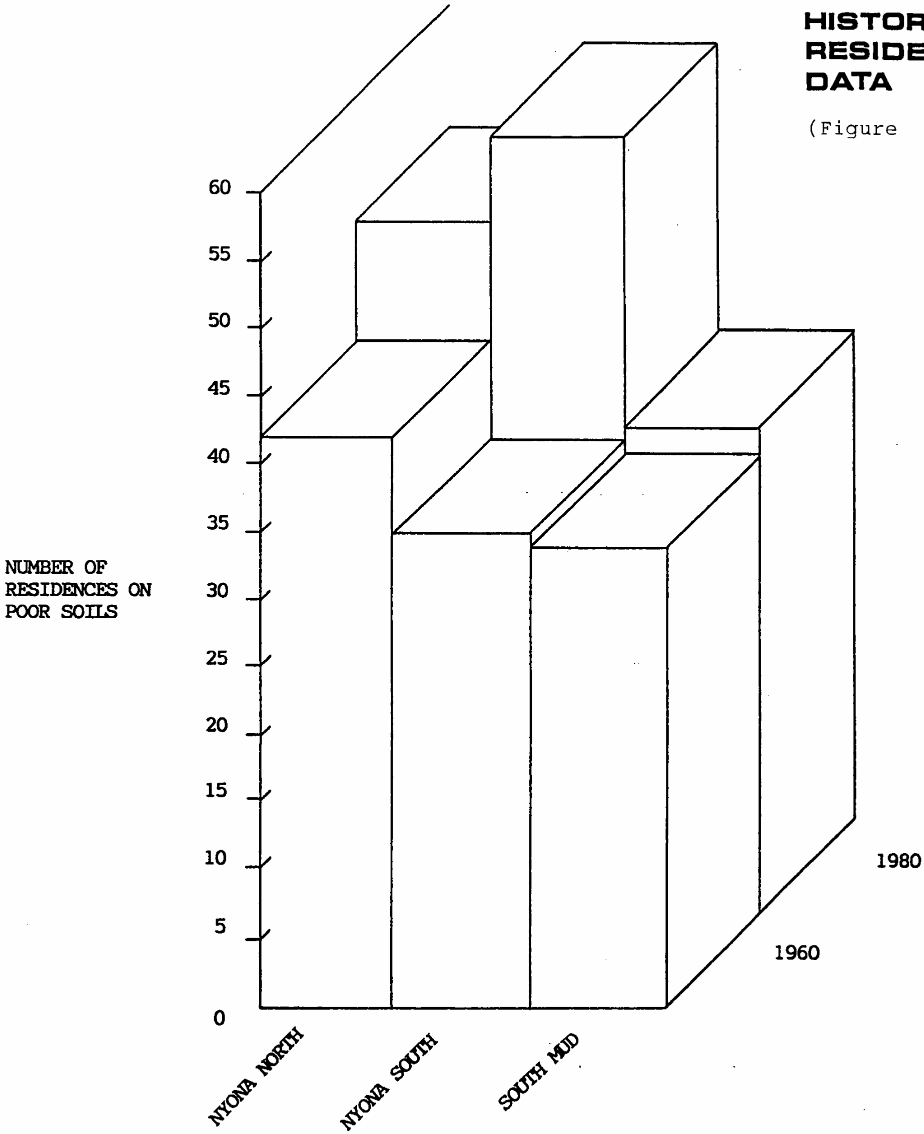
The assumption was made that septic tank type systems are in place for those residences located on saturated soils. General septic system efficiencies are based on the need for well drained soils necessary for proper treatment of sewage effluent. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well drained soils. It should be noted that seasonal fluctuations in the water table of poorly drained soils were not taken into account. Varying water table elevations and waste loading would be responsible for fluctuations in treatment success. Localized fecal coliform values likely increased due to a substantial increase in the summer population around the lake and fluctuations in the water table as well as residences in the watershed with septic systems that outlet directly into ditches.

The findings of this study presented in Table 24, indicate a continuing trend of building on saturated soils. South Mud Lake has shown an overall increase of 5% for residence situated on poorly drained soils. Nyona Lake demonstrated a 4% increase in residence on saturated soils between 1960 and 1980. Nyona Lake was further examined by basin. It was noted that residential development between two basins was comparatively equal over the 20 year study period. The south basin showed a dramatic increase in residence on saturated soils, 46% in 1960 to 53% in 1980, while the north basin exhibited an insignificant decline from 43% in 1960 to 42% in 1980.

Possible approaches to meet the current or future disposal needs with the objective of maintaining or improving water quality would include: 1) Lake-wide sanitary sewer system, 2) mound type septic systems and/or 3) pumping to suitable septic locations and 4) any of the above in combination with a constructed wetland or pond meadow system.
The **first**, likely most effective and costly method of waste handling would entail the construction of a lake community-wide sanitary sewer system with off-site waste treatment.
The **second** method, a mound type septic system would involve raising the septic tank above the saturated soil allowing for aerobic treatment of the sewage effluent.
The **third** method of waste treatment, which is currently being considered by many Nyona and South Mud residents, is a

HISTORICAL RESIDENCE DATA

(Figure 87)



procedure which involves pumping the waste effluent to a near by area with soils suitable for use in septic tank systems.

Although treatment is certainly not limited to the three management approaches discussed above, it was determined that these methods of waste treatment would effectively meet the goals of sewage disposal.

Residences must take on the responsibility of maintaining their own waste disposal systems. Drain fields should be inspected regularly and septic tanks should be pumped on a regular schedule. If it is determined that an engineering study should be undertaken for a new wastewater treatment system, the method and site selection should consider tertiary treatment using a constructed wetland system.

Table 23. **Poorly drained soils adjacent to Nyona and South Mud Lakes.**

Ad	ADRIAN muck
Ed	EDWARDS muck
Gf	GILFORD fine sandy loam
Hh	HISTOSOLS-AQUOLLS complex
Ho	HOUGHTON muck
Se	SEBEWA sandy clay loam
Wa	WALLKILL silt loam

Table 24. **1960 and 1980 Profiles of Residence Located on Saturated Soils;**

Location	Year	Total Residences	Residences on Saturated Soils	% Septic in Saturated Soils
South Mud	1960	38	34	89
	1980	46	43	94
Nyona	1960	174	77	44
	1980	226	108	48
Nyona N. Basin	1960	98	42	43
	1980	121	51	42
Nyona S. Basin	1960	76	35	46
	1980	105	57	53

Hydrology

The Nyona and South Mud watersheds are sub-drainage basins of the Wabash River Basin. According to the Fulton County Soil Conservation Service, the main water supply comes from ground water (Wisconsin till aquifer). The watershed of Nyona and South Mud Lakes receives an average annual precipitation of 37.5 inches with a standard deviation of 14 inches. June tends to be the wettest month with an average precipitation of 4.4 inches. On average, January is the driest month with a precipitation mean of 1.5 inches. Drainage gradients in the watershed range from 2.43 m/km in the Clemans Smith Ditch ending in the north basin of Nyona Lake to 1.55 m/km in the Rannel Ditch terminating in the south end of South Mud Lake.

Water regimes, according to the 1979 Cowardin et al classification system, range from temporary to permanent. Seventy eight percent of the wetlands located in the South Mud sub-watershed (Table 25 and 26) are of seasonal water regimes. Ninety five percent are small, less than ten acre, palustrine wetlands. Sixty-seven percent of the wetlands of the Nyona sub-watershed (Table 27 and 28) are of temporary water regime. Ninety-six percent are small with less than ten acre, palustrine wetlands. It should be noted that wetlands comprised only 81 acres (01%) of the total watershed area (reference Table 21). Palustrine defined here as wetlands less than 20 acres in size, averaging less than 6 foot in depth, and dominated by trees, shrubs, and/or emergent vegetation (Mitsch and Gosselink, 1986).

> **The past ten years have witnessed an extraordinary revival of interest in the drainage and reclamation of our non-arable swamp lands, and it is safe to predict that no movement will be attended with more beneficial or far reaching consequences.**

1914 "Drainage and Reclamation of Swamp and Overflowed Lands" Bulletin No. 2, Indiana Bureau of Legislative Information

It is estimated that 88% of the wetlands in the Wabash River Basin have been lost (Hamilton 1965). Losses are primarily attributed to drainage for agricultural production. The following tables are intended to illustrate the types of wetlands remaining in the Lake Bruce watershed, and focus attention on preserving these natural filters.

Table 25. **South Mud water regime characteristics**

Palustrine	Occurrence	%Totals
< 10 Acres	52	95
> 10 Acres	3	5
Totals	55	100
Type		
Forest	5	9
Emergent	49	89
Scrub / Shrub	1	2
Totals	55	100
Water Regime		
Temporary	11	20
Seasonal	43	78
Semi-permanent	1	2
Totals	55	100

Table 26. **South Mud sub-watershed wetland classification. An explanation of wetland class may be found in appendix A.**

By Class	> 10 Acres	Percent Class	Percent Total	< 10 Acres	Percent Class	Percent Totals
PFOA	0	0	0	3	6	6
PFOF	0	0	0	0	0	0
PFOC	0	0	0	2	4	4
PEMA	0	0	0	8	15	14
PEMF	0	0	0	1	2	2
PEMC	2	67	4	38	73	68
PSSA	0	0	0	0	0	0
PSSF	0	0	0	0	0	0
PSSC	1	33	2	0	0	0
Totals	3	100	6	52	100	94

Table 27. **Nyona water regime characteristics.**

Palustrine	Occurrence	% Totals
< 10 acres	90	96
> 10 acres	4	4
Totals	94	100
Type		
Forested	17	18
Emergent	70	75
Scrub \ Shrub	7	7
Totals	94	100
Water Regime		
Temporary	63	67
Seasonal	29	31
Semi-permanent	2	2
Totals	94	100

Table 28. **Nyona sub-watershed wetland classification.** An explanation of wetland class may be found in appendix A.

By Class	> 10 Acres	Percent Class	Percent Total	< 10 Acres	Percent Class	Percent Totals
PFOA	2	50	2	8	9	9
PFOF	0	0	0	0	0	0
PFOC	0	0	0	7	8	8
PEMA	1	25	1	49	55	53
PEMF	1	25	1	1	1	1
PEMC	0	0	0	18	20	19
PSSA	0	0	0	3	3	3
PSSF	0	0	0	0	0	0
PSSC	0	0	0	4	4	4
Totals	4	100	3	90	100	97

Natural Features

The Nyona/South Mud watershed falls within the Northern Lakes Natural Region as classified by Homoya (1985). This Natural Region is comprised of numerous fresh water lakes of glacial origin. Natural community types common to this region include bog, marsh, lake, sedge meadow, prairie and various deciduous forest types. The aquatic communities may be characterized by the presence of bulrush, marsh fern, cattails, pond weeds, spatterdock, Virginia arrow-arum, orchids, tamarack and various species of sedges. The typical forest community which at one time covered over half of this natural region is dominated by oak (chiefly red oak) and hickory. Other notable species include black; silver; sugar; and red maple, beech, American and red elm, green ash and cottonwood. Distinctive rare and/or endangered fauna of the area include spotted and Blanding's turtles, marsh wren, swamp sparrow and sandhill cranes. State rare and endangered plants reported in the South Mud Lake vicinity include established populations of sedges: Carex pseudo-cyperus and Carex bebbii.

Techniques useful in preserving these natural features include:

a. Avoid relocation of natural stream channels

b. Avoid building close to wooded ravines or stream banks.

c. Preserve natural vegetation adjacent to water areas. **This is a useful tool in preventing shoreline erosion!**

d. Avoid construction in or drainage of wetlands.

e. Avoid the use of on-site septic systems near the lakes or near drainages where there is potential for saturated soils.

Sediment and Nutrient Removal

In order to quantify the effectiveness of a control structure or constructed/enhanced wetland in removing sediments and nutrients, it is first necessary to develop a concept design for the site. Using the conceptual design, a flow model is developed. Flow models are used to determine a particular hydraulic characteristics for a given site at a given point in time. In this case, a flow model would be used to determine the surface loading rate (SLR). The SLR is used to derive the position of a particle (sediment) within a system at a any given point. With this information, a settling time can be predicted for particles entering a system based on distance and time rather than the specific gravity of a select range of particulates. The predicted sediment removal can then be determined by comparing the settling time needed to remove **X** amount of sediment from a system with the actual retention time for the system.

Nutrients are removed from a system in two basic ways: 1) by biotic processes in which they are utilized by plants and bacteria or; 2) by physical processes. Nutrients often travel through a system bonded to particulate matter, thus, as sediments are settled out, so are the nutrients attached to them.

Sedimentation is the settling out of soil particles which have been transported by air or water. Sedimentation occurs when the velocity of the transport medium (water) is slowed adequately and for a sufficient period of time (detention time) to allow for the soil particles to settle out. Larger heavy particles require high velocities or runoff to be transported and are quick to settle out. Smaller lighter soil particles are transported by suspension or by moving (tumbling) along the surface. Fine silts and clay materials are generally transported in suspension. These smaller soil particles are difficult to recover once eroded. Substantially lower velocities and greater detention times are required to settle these particles out.

Specific site design would be necessary to predict the actual amounts of nutrients transported through a system or to quantify the amount removed by a specific control structure. It is possible, however, to relate nutrient removal efficiencies from other structures designed by **Earth Source Inc.** At the Wilson Ditch site (near Culver, Indiana) for example, Mean total phosphorous was reduced 90%, while mean total nitrogen (nitrate/nitrite) was reduced 85% during the 1988 summer monitoring program. Mean total phosphorous was reduced 60% and mean total nitrogen was reduced 65% during the 1988 winter monitoring program. Similar nutrient removal rates could be expected for the constructed wetland sites for the Nyona/South Mud Lakes area.

Constructed Wetland Habitat

Potential exists for the construction of sediment/nutrient control structures to increase the overall wildlife habitat and production capabilities for the Nyona/South Mud Lakes area.

Primary fisheries production in the Nyona/South Mud Lakes area could benefit greatly by increased wetlands. Virtually all sport fish production is dependent on wetlands, either for spawning, cover or planktonic food production. Pike and sunfishes are major benefactors of increased wetland spawning area. They spawn in the wetlands and then return to the lake proper. The establishment of successful pike spawning habitat and population would help to control the overwhelming number of rough fish which have become dominate in both Nyona and South Mud Lakes.

Increased wetlands will draw waterfowl away from areas of moderate human use. Productivity is likely to increase while the "nuisance factor" decreases. Song birds are drawn to wetlands for a number of reasons: nesting structure provided by persistent emergent vegetation (cattails); security cover; and food production. Species such as the Great Blue Heron, Yellow Rail, Great White Egret, and Yellow-headed Blackbird (which are all state threatened, rare or of special concern) will locate near wetlands for many of the same reasons as their avian counter parts.

Fur-bearing animals like beaver, mink and muskrat depend on wetlands primarily for food, security cover and den sizes.

Muskrats will likely be the first fur-bearer to colonize a shallow constructed wetland. These prolific mammals do well in areas which have low water flow and emergent aquatic vegetation such as cattails. If muskrat den/foraging activity strays from or damages the constructed wetland and wetland structures it may become a nuisance, therefore, populations will require careful monitoring.

The mink is one of the most prized furbearers associated with wetlands. The habitat requirements of the mink are similar to those of the muskrat with one exception, the mink is a carnivore. Thus, mink population will usually mirror changes in muskrat population.

The beaver is another valued furbearer likely to colonize a constructed wetland in the Nyona/South Mud Lakes area. Again, if den/dam building activity strays from the constructed wetland it may become a nuisance, therefore, beaver populations will also require careful monitoring.

In summary, a constructed wetland is capable of increasing and supporting a diverse number of habitants. It should be noted that a constructed wetland is also constructed habitat. By design, these areas may attract species of special interest, through planned inclusions of required habitat components.

Constructed Options

For more than 50 years, wetlands have been identified as water purifying systems for natural lakes (van der Valk, et al 1978). Wetland vegetation, benthic organisms, and soils perform as traps, at least seasonally, for nutrients, suspended sediments, metals, pathogens, and many agricultural chemicals (Kadlec and Kadlec 1978). Thus, during the course of the Nyona and South Mud Lakes watershed study, a primary objective was to identify nutrient/sediment trap target sites on each of the contributing ditches. The primary criteria in selecting these sites were: location, topography, flow rates, soils, feasibility, current land use, size, environmental concerns, and sediment/nutrient loading characteristics of the drainage basin.

Seven sites were identified as potential locations for constructed options (Figure 88). Sites 1, 3, 2, 4 and 7 refer to constructed options on Nyona Lake. Site 3 is an upland site where land treatment is recommended to intercept sediment and animal waste prior to entering the Whitmore Ditch. Possible management practices for Site 3 are presented in Appendix C. Further discussion of Site 3, and graphic for Sites 3 and 4 are not provided. Sites 5 and 6 refer to constructed options on South Mud Lake. Constructed options on Nyona Lake will be discussed first.

Project Descriptions: Nyona Lake

Sites 1 and 2, Clemans-Smith Ditch and Whitmore Ditch

The Clemans-Smith Ditch is second only to the Whitmore Ditch in drainage area for the Nyona Lake Watershed. Water chemistry data from the Clemans-Smith Ditch indicated high values for total nitrogen and total suspended solids shown in Table 29. Sites 1 and 2 (Figure 89) have been conceptually designed to work in conjunction. Site 2, located on the Clemans-Smith Ditch is a series of drop structures, each planted with a dense stand of hydric vegetation, ie) cattails and rushes. This type of structure is designed to remove small suspended particles and nutrients. Site 1, located at the confluence of the Clemans-Smith and Whitmore Ditch is a sediment pond type structure. Vegetation in this "trap" would be dominated by floating deep water aquatic plants such as Water Lilies (*Nuphar spp.*). The location was selected to allow secondary treatment from site 2, and capture the greatest amount of drainage from both watersheds, as well as offering easy access for maintenance.

Site 4, Fouts Ditch

Site 4 is a potential constructed wetland site that is located on Fouts Ditch. This inlet exhibited relatively low flow. Excavation into organic soils would be necessary to construct this site.

Site 7, Tile - Wolfe Property

Site 7 is currently a marginally functional grass filter strip. This control structure is necessary to intercept a subterranean tile which is reportedly responsible for dumping a "nutrient rich" effluent into Nyona Lake during intense precipitation events. The proposed concept for this site (Figure 90) would widen the filter area and maintain uniform flow through a cattail/rush filter strip. Site selection in this case was simplified by the landowner's overwhelming support of the project.

<u>Project</u> <u>Descriptions:</u> **South Mud Lake**

The Zanger Ditch, although considerably smaller in drainage area than the Rannels Ditch, is responsible for the majority of sediments and nutrients entering South Mud Lake from the watershed. The reason for this is two-fold: 1) the recent ditch "cleaning" on Zanger Ditch has created a ditch flow capable of carrying sediment from the watershed to the lake and 2) there is a substantial functioning wetland on the Rannels Ditch just ahead of the lake.

Site 6, Zanger Ditch

Site 6 (Figure.91) consists of two small (<1 acre) constructed wetlands along the Zanger Ditch and a series of flow abatement baffles at the lake inlet. The constructed wetlands are a complex mix of deep water areas for sediment and bonded nutrient removal and vegetated baffles for nutrient uptake and flow abatement. The flow abatement baffles at the lake inlet will allow for greater detention time, as well as a secondary treatment stage for sediment and nutrient removal.

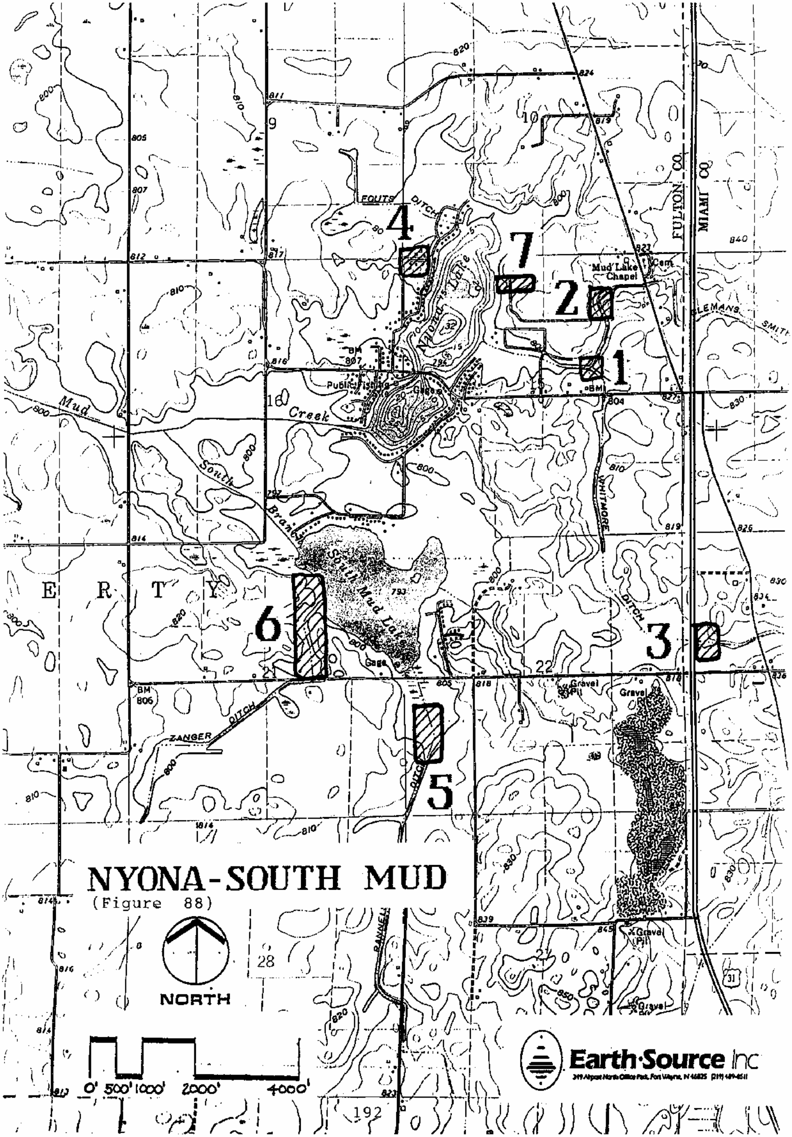
Site 5, Rannels Ditch

Site 5 (Figure 92) is a constructed wetland system. The constructed wetland would further buffer the lake from the Rannels Ditch which carries the greatest volume of water to the lake. A constructed wetland in this location would also expand and preserve the existing downstream wetland which contains several plant species that are rare and endangered in Indiana.

In summary, design and construction priority for Nyona Lake should be given to sites (1 and 2) and then site 3, 7 and 4. Design and construction priority for South Mud Lake should go to site 6 and then site 5.

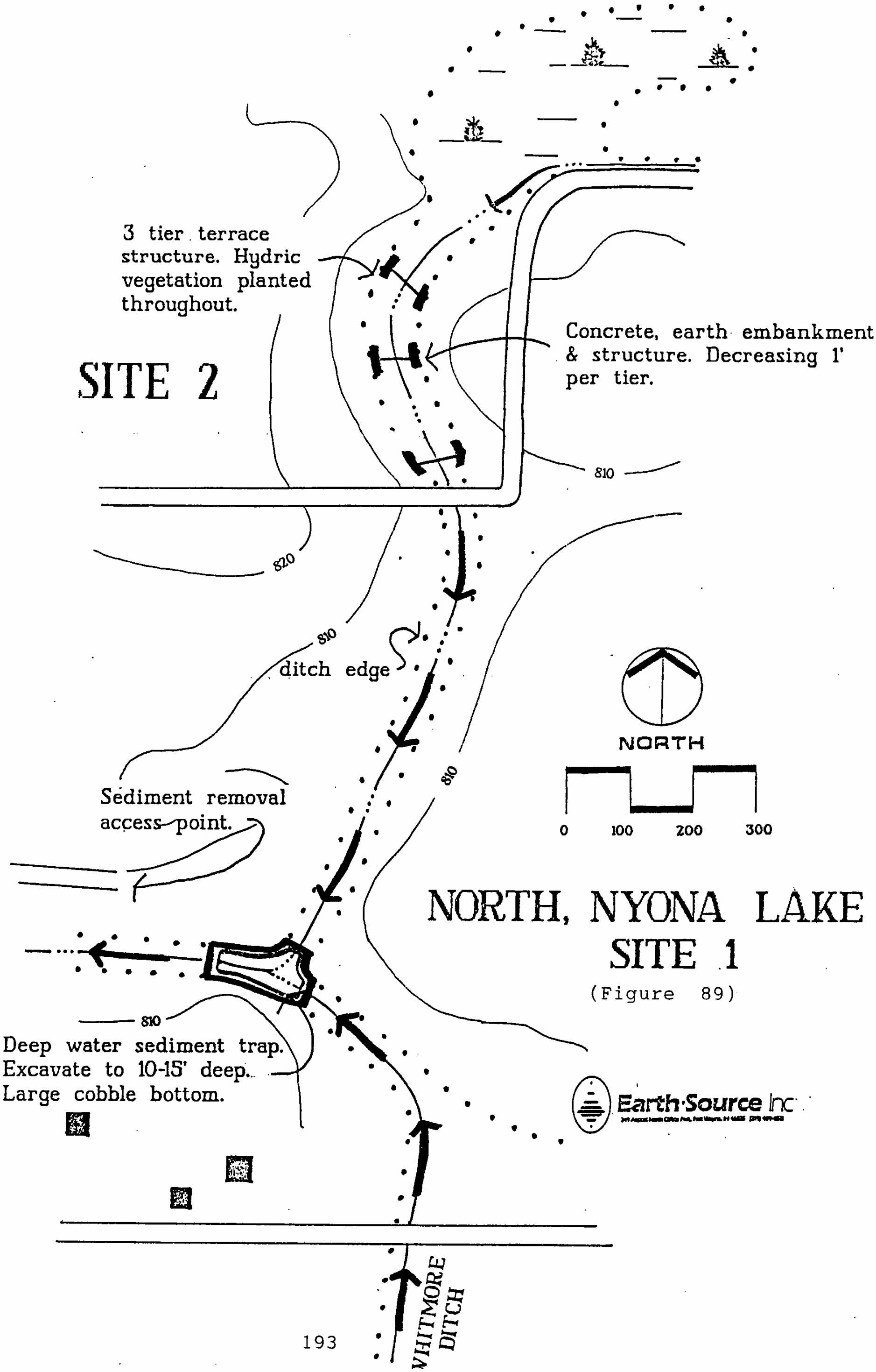
Table 29. **Water quality data collected from stream monitoring stations (03/1989).** Streams are listed according to flow (highest to lowest)

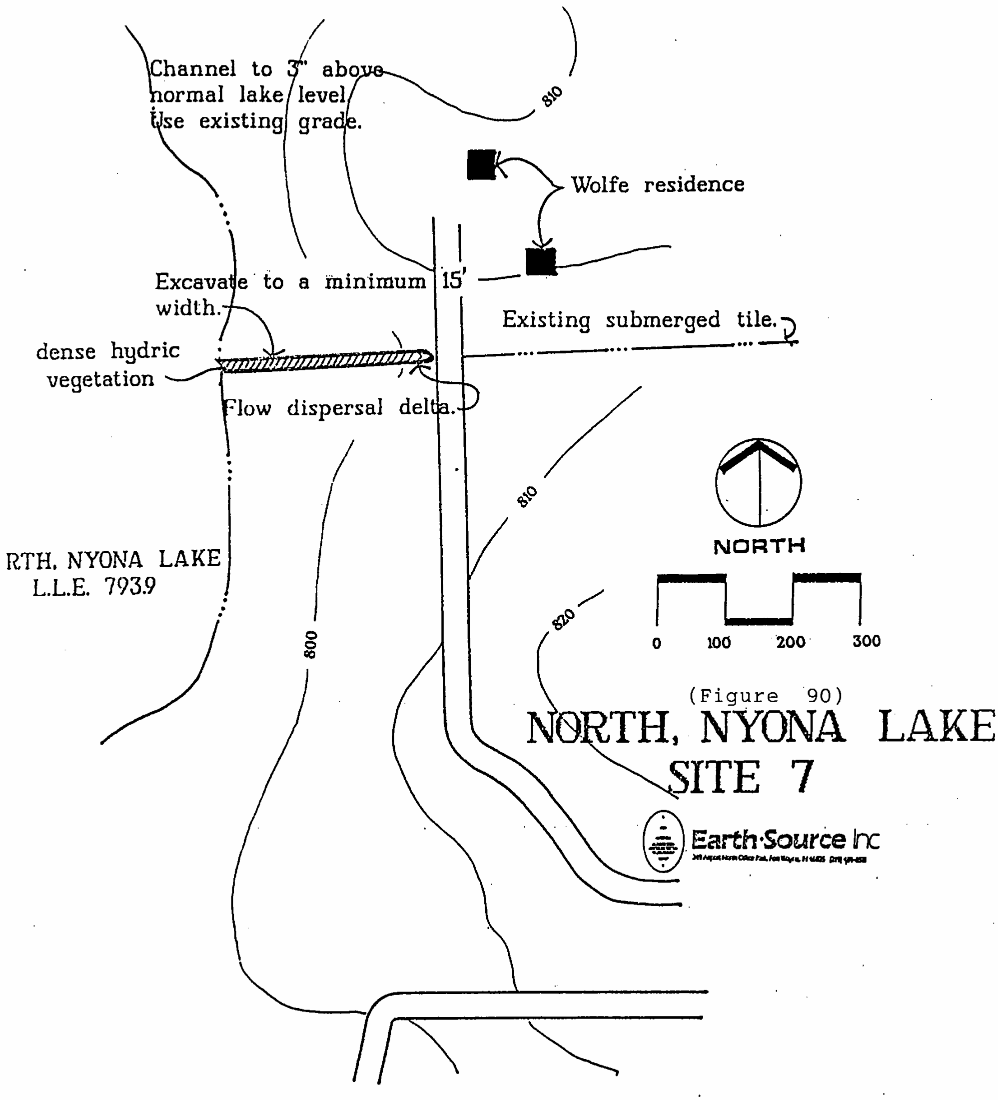
MONITORING STATION	TOTAL SUSPENDED SOLIDS (ppm)	TOTAL NITROGEN (ppm)	TOTAL PHOSPHORUS (ppm)
Fouts Ditch	8.00	3.17	**0.14**
Clemens Smith Ditch	**24.00**	**5.18**	0.06
Whitmore Ditch	14.00	2.41	**0.13**
C. Brown Ditch	8.00	1.96	0.08
Zanger Ditch	**18.00**	2.18	0.12
Rannels Ditch	10.00	**3.47**	0.10



NYONA-SOUTH MUD

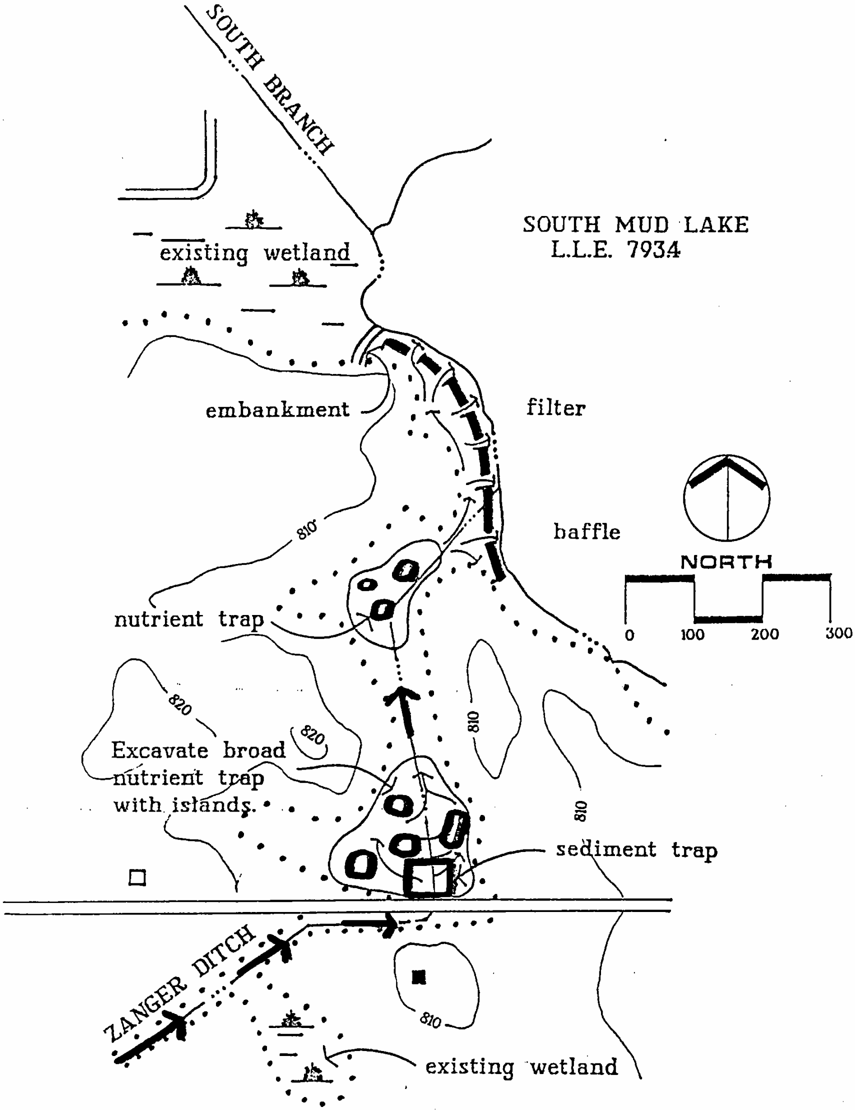
(Figure 88)


3 tier terrace structure. Hydric vegetation planted throughout.
SITE 2
Concrete, earth embankment & structure. Decreasing 1' per tier.
810
820
810
ditch edge
NORTH
0
100
200
300
810
Sediment removal access point.
NORTH, NYONA LAKE
SITE 1
(Figure 89)
810
Deep water sediment trap. Excavate to 10-15' deep. Large cobble bottom.
Earth·Source Inc
WHITMORE DITCH



(Figure 90)

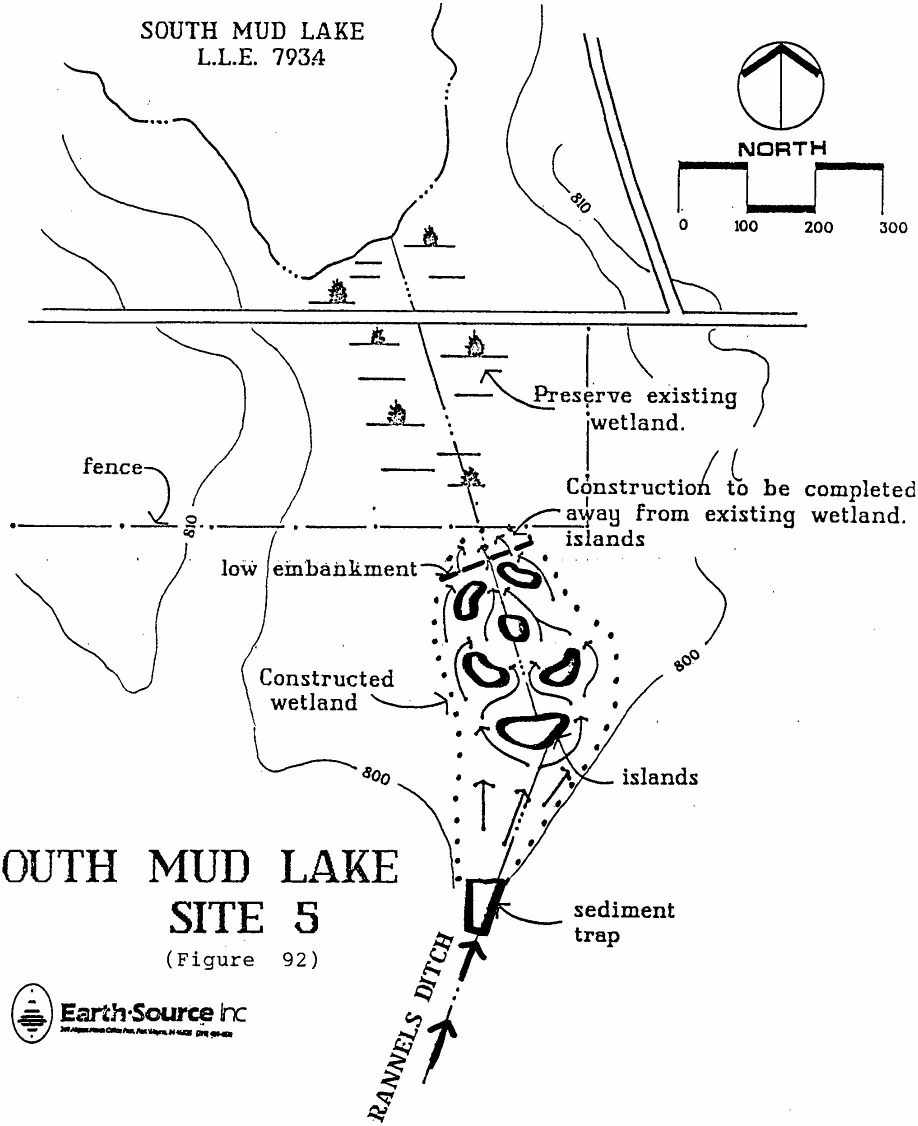
NORTH, NYONA LAKE
SITE 7



SOUTH MUD LAKE
SITE 6

Earth·Source Inc

(Figure 91)



SOUTH MUD LAKE
SITE 5
(Figure 92)

Earth·Source Inc

Cost Estimates for Constructed Options

The following estimates are offered to represent the anticipated cost factors for construction of suggested sites 1 through 7. During final design, some additional factors may become apparent. Since the sites are relatively small, open, and easily accessed, base maps can most feasibly be generated by field survey methods. This cost item should be part of a proposed design fee. For final design and construction documents, and allowance of 15% to 20% of construction cost should be added to these estimates. Additional cost of services should be added for bidding, construction monitoring and construction administration if required by the funding agencies. Other additional cost items not included in these estimates are as follows: 1. Land cost (if any). 2. Attorney's fees to prepare landagreements. 3. Property line surveys or descriptions. 4. Preparation of permits such as to the Department of the Army, IDNR Division of Water, County Drainage Boards, Indiana Department of Environmental Management. 5. Operation and maintenance of sites and access thereto.

Priority recommendations for each site, have been made based upon the need, feasibility, availability of the site, and other considerations discussed in construction.

Site 1 Nyona-Whitmore Ditch

Cost items include excavation, cobble bottom (partial), bank protection, plantings for erosion control/bank protection, construction and maintenance road extension, and fence.
Estimated cost range: $16,000-21,000
Priority recommendation: **High**

Site 2 Nyona - Clemans-Smith Ditch

Cost items include concrete drop structures (3), rip rap, site grading, fence, restoration and seeding, and wetland plantings.
Estimated cost range: $32,000-40,000
Priority recommendation: **High**

Site 3 Nyona - Whitmore Ditch (Miami County)

Cost items include excavation, site grading, restoration, erosion control, fence.
Estimated cost range: $25,000-35,000.
Priority recommendation: **High**

Site 4 Nyona - Fouts Ditch

Cost items include excavation, sediment/erosion control, wetland plantings, restoration and seeding, (No water level control structure).
Estimated cost range: $35,000-40,000
Priority recommendation: **Low to moderate**

Site 5 South Mud - Rannels Ditch

Cost items include excavation for sediment trap, excavation, restoration, and seeding, wetland plantings, fence, down stream sediment trap, site access drive and low embankment.
Estimated cost range: $42,000 - 48,000
Add for pipe, water control structure and spillway, $13,000.
Priority recommendation: **Moderate to high**

Site 6 South Mud - Zanger Ditch

Cost items include excavation for sediment trap, site excavation (nutrient trap), earth fill for baffle filters, restoration and seeding, wetland plantings, and fence.
Estimated cost range: $ 35,000 - 45,000.
Priority recommendations: sediment trap: **highest**
nutrient trap: **high**
baffle filter (at lake): **moderate**

Site 7 Nyona Lake - Wolfe property

Cost items include: excavation, rock dispersal chamber, restoration, seeding and wetland plantings.
Estimated cost range: $5,000 - 6,500
Priority recommendation: **high**
(mostly due to simplicity, low cost, and availability of site)

Permitting

Beyond property ownership, many governmental agencies may have jurisdiction over private property. For example, drainage may be regulated by the County Surveyor (Table 30). Water issues, particularly construction in a floodway, is regulated by the Indiana Department of Natural Resources Division of Water, and the United States Department of the Army, Corps of Engineers. Excavation below legal lake level (Nyona 793.91', mean sea level datum, and South Mud 793.42', mean sea level datum) or any ditch modification within .5 miles of Nyona Lake and South Mud Lake, will require authorization by the IDNR, Division of Water, Lake Section. The Corps of Engineers will require permitting and Water Quality Certification by the IDEM, Office of Water Management for construction in wetland areas. The Corps of Engineers (and the Divisions of Water) may require permitting if any construction impounds water. A list of different agency contacts, addresses, and telephone numbers may be found in appendix B.

C. Brown Ditch	South Mud Lake
Clemens Smith Ditch	Nyona Lake
Fouts Ditch	Nyona Lake
Mud Creek Ditch	Outlet
Rannels Ditch	South Mud Lake
Whitmore Ditch	Nyona Lake
Zanger Ditch	South Mud Lake

Table 30. **Regulated county drains of the Nyona; South Mud watershed.**

Conclusions & Recommendations 4.

CONCLUSIONS AND RECOMMENDATIONS

NYONA LAKE

Water Quality

Water quality problems were evident at Nyona Lake as early as the first data collection in 1964. Algal blooms were common during midsummer and dominated by blue-green algae. The DNR considered aquatic weeds in nearshore areas to be of problem proportions and suggested implementation of a control program. The lake was displaying clear signs of advancing eutrophication.

Eutrophication has continued to advance progressively since at least 1964. Aquatic weeds have continued to expand and to pose problems in nearshore areas as the exotic Eurasian watermilfoil has replaced the native coontail as the dominant plant in the lake. Although the state eutrophication index was 54 in both 1975 and 1989, it is likely that water quality has continued deteriorate. This index likely provides a conservative estimate of the actual increase in trophic state because rapid expansion of aquatic weeds and their ability to take up nutrients has resulted in lower total phosphorus and greater water clarity in open water areas of the lake during 1989 in spite of no evidence of a reduction in the rate of nutrient loading to the lake from the watershed. Algal blooms dominated by blue-green algae are still common during midsummer, and an algal feeding rough fish characteristic of eutrophic lakes, gizzard shad, increased throughout the 1960's and 1970's and now makes up greater than 40% of total fish abundance in Nyona Lake.

While both septic and stream drainage have contributed to the eutrophication of Nyona Lake, the latter is likely of greater overall magnitude. Fecal coliform bacteria exceeded state standards on only one occasion between 1966 and 1989 suggesting that direct septic contamination of the lake is minor. Because most of the shoreline residences are located over highly organic and water saturated soils, septic systems are likely not operating efficiently. It is recommended that residents make a concerted effort to have their drain fields inspected regularly and to keep their septic tanks pumped. Residents can reduce nutrient loading to the lake by using phosphate-free detergents for both clothes and dishes. Simple irrigation of lawns using lake water will provide sufficient nutrients to sustain lawn growth. Such simple modification of practices can reduce the contribution each resident makes to the phosphorus and nitrogen loading of the lake.

Although the density of houses is lower on the north basin of Nyona Lake, phosphorus concentrations in the bottom sediments are greater than observed in the south basin. All inlet streams enter Nyona Lake in the north basin and appear to be the major nutrient loader to the lake. It is obvious that such stream derived nutrients also contribute significantly to the eutrophication to the south basin as water movement through the system is directed from the north basin to the only lake outlet at the southwestern corner of the south basin.

Water quality improvement in Nyona Lake must address both watershed and in-lake management issues. Implementation of in-lake management practices may provide short term relief from weed problems and other manifestations of eutrophication but will not provide a long term solution without addressing nutrient and sediment imputs to the lake from the watershed. It is suggested that no long term in-lake management solutions be implemented until nutrient and sediment loading from the watershed is reduced dramatically.

Aquatic Weeds

As early as 1964 aquatic weeds were considered to be a problem in Nyona Lake. Chara formed a dense band around the lake at 1-5 feet water depth and was replaced by coontail as the dominant problem plant in water 5-10 feet deep. Weeds were extremely sparse in water greater than 10 feet deep. Based on similar findings in 1966 and 1970 a chemical control program was initiated in the early 1970's that targeted Chara growth in nearshore areas.

Chara was virtually absent by 1989, but aquatic weeds have worsened since the mid 1970's as coontail has been almost completely replaced by the exotic Eurasian watermilfoil. Currently, weeds choke 80-100% of the water column under 16% of the surface area (12.05 acres) of the north basin and 19% of the south basin (5.62 acres). Weed problems are restricted to water depths less than 5 feet in both the north and south basins with 61% of the 0-5 foot contour in the north and 62% in the south being choked with weeds. Most stands of problem aquatic weeds are less than 2 feet tall.

A number of techniques can be implemented to control problem weeds (Crisman 1986, Moore and Thornton 1988). Excessive growth can be cut mechanically and removed from the lake. Although some nutrients can be removed from the lake, this is no permanent solution because roots and seeds are left intact, and finding a suitable site for disposal of the cut material is often difficult. Residents could continue the chemical control program as in previous years.

This is merely a stop gap measure that can do more harm than good. Nutrients released from decaying vegetation enter the water column and can promote phytoplankton blooms. Numerous cases exist of excessive chemical treatment that shifts lakes to algal dominance and a whole new range of management problems.

Given that weed problems are restricted mostly to water less than 5 feet deep, it is proposed that the outlet dam be modified to permit a lowering of water level by 5 feet during winter. Such drawdowns can freeze weed roots, hinder germination of seeds, and oxidize and compact organic nearshore sediments. Although some plant species may be resistant to drawdowns and may actually increase afterward, the major plant taxa in Nyona Lake (Eurasian watermilfoil and coontail) can be controlled by the management technique (Moore and Thornton 1988).

There are some potential negative effects of drawdown that should be examined. Algal blooms could occur as a result of nutrient release from plant tissue. As discussed earlier, plants compete with algae for nutrients and removal of macrophytes can free nutrients for algal utilization. Oxidation of sediments and plant matter can also lead to winter fish kills due to reduction of oxygen during decomposition if the period of ice cover is especially long. Fish populations can also be affected through alteration of benthic invertebrate communities and loss of plant cover as protection from predators. The latter fish effects are not considered likely at Nyona Lake given the fact that the plant cover is so extensive that such areas are little utilized by fish. It is strongly recommended that any drawdowns be coordinated with the district fishery biologist from the Division of Fish and Wildlife, DNR.

Drawdown at Nyona Lake could be a reasonably simple process. Removable boards in the dam could be taken out during early fall to drop water level during winter and be replaced and locked before early spring rains. In this way flood protection would not be compromised, and the lake would be at its current legal limit in time for summer recreational activities. Following initial dam modifications, continued weed control would be cost free. The precident for establishing a modified winter legal water level has already been established for at least one lake in northern Indiana (Sylvan), where a series of winter drawdowns were performed during the late 1970's and early 1980's.

Any weed control at Nyona Lake must be approached cautiously. Without reducing nutrient loading to the lake from the watershed and possibly the lake sediments, algal blooms may replace weed problems. The problem of nutrient recycling from lake sediments could pose the greatest problem in the northern and northeastern sections of the north basin, shallow areas currently completely colonized by macrophytes. Removal of macrophytes would expose sediments to wave action and possibly result in increased internal nutrient cycling. If sediment nutrient release proves to be a problem, then nutrient inactivation or bottom sealing should be considered as management options. The best way to insure that algal problems do not follow macrophyte problems is to avoid overly zealous complete control of macrophytes in the lake.

Fish

The DNR fish survey of 1964 noted that there had been a steady decline in bluegill since at least 1949 and that removal of excessive weed growth in nearshore areas would likely improve bluegill populations. Gizzard shad populations expanded markedly between 1966 and 1970 prompting DNR to suggest that a selective eradication program be implemented. A selective shad kill using rotenone was employed in 1971, but this proved ineffective at long term reduction of shad importance in the lake. Since 1980 shad has been the dominant fish in the lake on a weight basis followed by white sucker and redear, a possible competitor with bluegill. The significance of the replacement of bluegill by redear was not examined, but may not be great given that many anglers have trouble distinguishing between these two species. The high biomass of shad is particularly worrisome and is taken as a sign of advancing eutrophication. Shad feed heavily on algae and once in lake systems can promote dominance by blue-green species due to their inefficient digestive system.

Fish stocking has been undertaken a number of times at Nyona Lake. During the 1950's, bluegill, crappie, redear and largemouth bass were stocked, and an additional stocking of bass took place in 1971 following rotenone removal of shad. The most recent efforts have concentrated on introduction of northern pike. Although present in the lake prior to 1949, the recent stocking of this species in 1986 as a predator on shad apparently was unsuccessful.

A majority of the fish in both the north (57%) and south (58%) basins are restricted to water depths of 3-5 feet during midsummer due to serious oxygen depletion in deeper waters. It is likely that attempts at fishery management will be only marginally successful until nutrient loading to the lake is reduced significantly. Overall, the DNR has done an excellent job managing the Nyona Lake fishery in spite of severe limitations in both funding and manpower. It is recommended that lake residents encourage the State of Indiana to provide additional funding support for the type of service offered by the DNR.

Basin Infilling

Of the streams sampled during March 1989, Fouts Ditch contributed the most total phosphorus and suspended sediment to the lake. Our sediment investigations indicated that both Fouts and Martin-Whitmore Ditches have contributed significant nutrient and sediment loadings to the north basin of Nyona Lake in recent years. Although the density of houses is less around the north basin, phosphorus concentrations in lake sediments are greater than in the more populated south basin indicating the overriding importance of stream delivered nutrients on the nutrient budget of Nyona Lake. Fortunately, heavy metal and herbicide/pesticide contamination of sediments from watershed sources was not observed.

Sediments of the north basin were not only a little more inorganic, but the basin as a whole displayed a greater degree of infilling during the past 35 years than the south basin. All five-foot depth contours less than 15 feet deep increased in aerial extent in the north basin between 1954 and 1989 with the greatest percentage increase (42%) being displayed by the 5-10 foot interval. A similar pattern was noted in the south basin for depths less than 10 deep with the greatest percentage increase (53%) recorded for the 5-10 foot contour. While basin infilling was fairly uniform throughout the south basin, that of the north basin was heterogeneous with maximal sedimentation noted near the inlets of Fouts and Martin-Whitmore Ditches. It is obvious that a majority of the sedimentation in the north and likely the south basins is directly related to stream input of watershed sediment especially during spring rain events.

It is recommended that particular attention be paid to reducing the loading of nutrients and sediments by Fouts and Martin-Whitmore Ditches. In addition to watershed control measures to be discussed later, aquatic weeds at the mouths of ditches should be left intact as a nutrient and sedimentation barrier. Removal of such plant growth will speed delivery of both parameters into the lake thus accelerating both basin infilling and eutrophication.

If drawdown is used as a management option for aquatic macrophytes as discussed above, submergent weeds in front of inlet stream mouths will also be destroyed. It is recommended that a mixed species assemblage of emergent plant species be planted at stream mouths to serve as a nutrient and sediment trap. Cattails, for example, would likely be little affected by periodic winter drawdowns (Moore and Thornton 1988).

As it has also been demonstrated that nearshore erosion via wave action has contributed to basin infilling, it is recommended that homeowners be encouraged to leave a fringe of emergent vegetation along the entire length of their lake front to serve as an erosion barrier. Homeowners should also inspect their shoreline for evidence of erosion and make appropriate repairs immediately. Finally, boaters should be encouraged to reduce speed when near shore in order to minimize wave generation and subsequent erosion of shoreline areas.

SOUTH MUD LAKE

Water Quality

Water quality problems were evident at South Mud Lake as early as the first data collection in 1965. Although algal blooms were not mentioned, the DNR considered aquatic weeds in nearshore areas to be of problem proportions and suggested implementation of a control program. The lake was displaying clear signs of advancing eutrophication.

Eutrophication has continued to advance progressively since at least 1965. Aquatic weeds have continued to pose problems in nearshore areas especially the exotic Eurasian watermilfoil. Although the eutrophication index decreased from 66 to 49 between 1975 and 1989, it is not likely that the degree of eutrophication has declined markedly during the period. Because the index is based principally on parameters taken from open water, it is likely that expanding aquatic weeds effectively compete with algae for limiting nutrients such as phosphorus, thus reducing open water concentrations of parameters on which the index is based. Algal blooms dominated by blue-green algae in 1989 were, and an algal feeding rough fish characteristic of eutrophic lakes, gizzard shad, increased throughout the 1960's and 1970's and now makes up greater than 40% of total fish abundance in South Mud Lake.

While both septic and stream drainage have contributed to the eutrophication of South Mud Lake, the latter is likely of greater overall magnitude. Although historical data on fecal coliform bacteria are lacking, the 1989 values were well within state standards suggesting that direct septic contamination of the lake is minor. Because most of the shoreline residences are located over highly organic and water saturated soils, septic systems are likely not operating efficiently. It is recommended that residents make a concerted effort to have their drain fields inspected regularly and to keep their septic tanks pumped. Residents can reduce nutrient loading to the lake by using phosphate-free detergents for both clothes and dishes. Simple irrigation of lawns using lake water will provide sufficient nutrients to sustain lawn growth. Such simple modification of practices can reduce the contribution each resident makes to the phosphorus and nitrogen loading of the lake.

Cattle are undoubtedly more important nutrient loaders to South Mud Lake than the human population along the shore. As early as 1965 the DNR recognized that permitting cattle to have direct contact with the lake along the southwestern shore promoted heavy siltation and destruction of macrophyte beds. At that time it was suggested that a fence be built to keep cattle from the lake. The problem was still evident in 1989. Given the size of the herd, it is suggested that direct nutrient loading to the lake from cattle feces far exceeds any contribution from septic tanks. It is recommended that cattle be kept totally away from the lake.

Streams are the dominant nutrient loaders to South Mud Lake. Zanger Ditch appears to be the major contributor of nutrients to the lake, a role that has likely increased recently as a result of dredging along its length and a failure to stabilize either the stream bed or banks. Further evidence of the importance of this stream to the eutrophication of South Mud Lake is that a vast majority of basin infilling between 1948 and 1989 occurred near the inlet of Zanger Ditch and resulted from stream borne sediments.

Water quality improvement in South Mud Lake must address both watershed and in-lake management issues. Implementation of in-lake management practices may provide short term relief from weed problems and other manifestations of eutrophication but will not provide a long term solution without addressing nutrient and sediment imputs to the lake from the watershed. It is suggested that no long term in-lake management solutions be implemented until nutrient and sediment loadings from the watershed are reduced dramatically.

Aquatic Weeds

As early as 1965 aquatic weeds were considered to be a problem in South Mud Lake. Eurasian watermilfoil formed a dense band around the lake at 1-5 feet water depth and was the dominant problem plant in the lake. Weeds were extremely sparse in water greater than 10 feet deep. The 1965 survey as well as those of 1973 and 1980 produced similar findings with all suggesting implementation of a chemical control program to reduce plant biomass and improve the fishery.

Currently, weeds choke 80-100% of the water column under 26% of the surface area (26 acres) of the lake, and weed problems are restricted to water depths less than 5 feet. Most stands of problem aquatic weeds are less than 2 feet tall.

A number of techniques can be implemented to control problem weeds (Crisman 1986, Moore and Thornton 1988). Excessive growth can be cut mechanically and removed from the lake. Although this reduces plant biomass and possibly nutrients, this is no permanent solution because roots and seeds are left intact, and finding a suitable site for disposal of the cut material is often difficult. Residents could implement a chemical control program. This is merely a stop gap measure that can do more harm than good. Nutrients released from decaying vegetation enter the water column and can promote phytoplankton blooms. Numerous cases exist of excessive chemical treatment that shifts lakes to algal dominance and a whole new range of management problems.

Given that weed problems are restricted mostly to water less than 5 feet deep, it is proposed that the outlet dam be modified to permit a lowering of water level by 2-5 feet during winter. Such drawdowns can freeze weed roots, hinder germination of seeds, and oxidize and compact organic nearshore sediments. Although some plant species may be resistant to drawdowns and may actually increase afterward, the major plant taxon in South Mud Lake (Eurasian watermilfoil) can be controlled by the management technique (Moore and Thornton 1988).

There are some potential negative effects of drawdown that should be examined. Algal blooms could occur as a result of nutrient release from plant tissue. As discussed earlier, plants compete with algae for nutrients and removal of macrophytes can free nutrients for algal utilization. Oxidation of sediments and plant matter can also lead to winter fish kills due to reduction of oxygen during decomposition if the period of ice cover is especially long. Fish populations can also be affected through alteration of benthic invertebrate communities and loss of plant cover as protection from predators. The latter fish effects are not considered likely at South Mud Lake given the fact that the plant cover is so extensive that such areas are little utilized by fish. It is strongly recommended that any drawdowns be coordinated with the district fishery biologist from the Division of Fish and Wildlife, DNR.

Drawdown at South Mud Lake could be a reasonably simple process. Removable boards in the dam could be taken out during early fall to drop water level during winter and be replaced and locked before early spring rains. In this way flood protection would not be compromised, and the lake would be at its current legal limit in time for summer recreational activities. Following initial dam modifications, continued weed control would be cost free. The precident for establishing a modified winter legal water level has already been established for at least one lake in northern Indiana (Sylvan), where a series of winter drawdowns were performed during the late 1970's and early 1980's.

Any weed control at South Mud Lake must be approached cautiously. Without reducing nutrient loading to the lake from the watershed and possibly the lake sediments, algal blooms may replace weed problems. The problem of nutrient recycling from lake sediments could pose the greatest problem in the eastern section of the the lake, a shallow area currently completely colonized by macrophytes. Removal of macrophytes would expose sediments to wave action and possibly result in increased internal nutrient cycling. If sediment nutrient release proves to be a problem, then nutrient inactivation or bottom sealing should be considered as management options. The best way to insure that algal problems do not follow macrophyte problems is to avoid overly zealous complete control of macrophytes in the lake.

Fish

Although the fish assemblage was 52% largemouth and bluegill in 1965-66, the DNR was concerned that 23% of total fish abundance was made up of undesirable species. The importance of one undesirable species, gizzard shad, increased between 1965 and 1970, but between 1970 and 1973 its population quadrupled. During the same three year period, the population of another rough fish, white sucker, doubled. Such changes were accompanied by reduction in largemouth bass and white bass populations and indicate a significant increase in the degree of eutrophication during the early 1970's. By 1984, gizzard shad had increased to greater than 40% of total fish abundance in South Mud Lake.

Tiger muskellunge were stocked into the lake in 1980 and 1983 in an effort to increase the predator fish population. Such action was felt especially important given that two of the dominant native predators, largemouth bass and white bass, had declined in importance in recent years. Unfortunately, the success of such stocking efforts has not been good.

A majority of the fish in South Mud Lake during July 1989 (48%) were restricted to water depths of 3-5 feet due to serious oxygen depletion in deeper waters. It is likely that attempts at fishery management will be only marginally successful until nutrient loading to the lake is reduced significantly. Overall, the DNR has done an excellent job managing the South Mud Lake fishery in spite of severe limitations in both funding and manpower. It is recommended that lake residents encourage the State of Indiana to provide additional funding support for the type of service offered by the DNR.

Basin Infilling

Of the streams sampled during March 1989, Zanger Ditch contributed the most total phosphorus and suspended sediment to the lake. Our sediment investigations indicated that this ditch has historically contributed significant nutrient and sediment loadings to the lake. Fortunately, heavy metal and herbicide/pesticide contamination of sediments from watershed sources was not observed.

Sediments of South Mud Lake are the most inorganic of any natural lake in northern Indiana that we have studied and approximate those of reservoirs receiving high sediment loading from the watershed. South Mud Lake has experienced a great deal of infilling since 1948. All five-foot depth contours less than 15 feet deep increased in aerial extent between 1948 and 1989 with the greatest percentage increase (53%) being displayed by the 10-15 foot interval. Basin was heterogeneous with maximal sedimentation noted near the inlet of Zanger Ditch. It is obvious that a majority of the sedimentation in South Mud Lake is directly related to stream input of watershed sediment especially during spring rain events.

It is recommended that particular attention be paid to reducing the loading of nutrients and sediments by Zanger Ditch. In addition to watershed control measures to be discussed later, aquatic weeds and the forested wetland at the mouth of the ditch should be left intact as a nutrient and sedimentation barrier. Removal of such plant growth will speed delivery of both parameters into the lake thus accelerating both basin infilling and eutrophication. It is recommended that homeowners be encouraged to leave a fringe of emergent vegetation along the entire length of their lake front to serve as an erosion barrier. Homeowners should also inspect their shoreline for evidence of erosion and make appropriate repairs immediately. Finally, as stated earlier, cattle pastured along the southwestern shore of the lake have destroyed aquatic weed beds in addition to serving as important nutrient and loaders to the lake. Boating activities appear to have had little detrimental action on the lake.

CONCLUSIONS AND RECOMMENDATIONS

THE WATERSHED

It is apparent that nutrient and sediment loading from the Nyona Lake and South Mud Lake watersheds has not decreased over recent history. It is also apparent that the lakes have met the increased availability of nutrients by the tremendous expansion of submergent macrophytes. Successful aquatic weed control is dependent on curtailing the flow of nutrients and sediment bonded nutrients to the lakes from the watershed. For this reason, priority should be given to one or more of the major constructed options on each lake prior to any significant aquatic weed control programs. Allowing aquatic weeds to persist until one or more of the major constructed options is in operation will also serve to remove excess nutrients stored in the lake system.

<u>Nyona Lake</u>

1. Preserve the wetland area and forested buffer on the north/northeast end of the lake. This could be done even if new homes are built there. A `setback' from the lake should be required for all future building.

2. Inspect septic systems of all sites identified as occurring on saturated soils. This includes nearly all of the shoreline development on the south basin, and part of the shoreline development of the north basin.

3. Inspect the land parcel southeast of the lake for further evidence that there is significant sediment contribution to the ditch and lake. Sediment curtains could be established in the short-term, while permanent vegetative cover is established in critical areas.

4. A monitoring program should be implemented in upstream segments of the Clemens Smith and Whitmore Ditches just west of U.S. 31. Upstream monitoring would more precisely locate sediment and nutrient loading zones of the watershed. Once identified, management practices could be implemented. Samples should be analyzed for total phosphorus, ortho-phosphorus, total nitrogen, nitrate/nitrite, total suspended solids, coliform and streptococcal bacteria. (Upstream sampling is beyond the scope of this study)

5. Continue to encourage minimum and no-till farming practices in the upland portion of the watershed. Other land treatment practices, especially stream/ditch bank stabilization, should be pursued. This could be accomplished by establishing grassed ditch borders (filter strips), and, in more extreme cases, structural or riprapped solutions. Excavate and maintain sediment

traps that may be located at easily accessible intervals, such as near roads. (Other Conservation Practices are listed in Appendix C. These practices will be detailed in individual farm Conservation Plans, as required by the 1985 Farm Bill to be implemented by 1995).

6. Construct trapping systems in the Whitmore, and Clemens-Smith Ditches near the Lake as described in the section on Constructed Options.

7. Consider other Constructed Options as described in that Section of this report.

8. Do not permit any new drainage system to be constructed in the northeast corner of Nyona Lake.

9. Get cattle out of the ditches and ditch banks, perhaps, by helping landowners find financial assistance to fence and construct filter strips. Also, Filter strip or otherwise intercept runoff from animal feedlots.

10. Require sediment curtains, such as erosion control mats and straw bale filters, for all new construction around the ~~Lake.~~ lake,

11. Wetlands constitute less than 1 percent of the watershed land. This is apparently a natural shortcoming in this region and may also be an important natural factor in the lack of water quality protection in the lakes. Certainly, this emphasizes the critical importance of land treatment in the agricultural watershed and the necessity of preserving and increasing the number of wetlands throughout the watershed.

12. Consider engaging an engineering study for a lake-wide sanitary sewer district that considers several alternative methods of wastewater disposal.

South Mud Lake

1. Preserve the outstanding marsh in the northeast quarter of the lake.

2. Establish a setback requirement for all future development around the lake.

3. Construct sediment traps in Zanger Ditch as an immediate measure to stall heavy sediment inputs until bank stabilization or constructed options are put into place.

4. Do not allow ditching through the marsh at the end of Rannels Ditch. Construct the trap suggested above this marsh.

5. Fence the cattle out of the lakes south shore. Aid the landowner in locating financial assistance for this project. A minimum buffer of 30'-50' is suggested. Monitor the shoreline for natural restoration. Provide additional plantings (Bullrush & Rush) if natural restoration needs assistance. This may be an opportunity to introduce other hydrophytes before loosestrife or a cattail monoculture establishes.

6. The establishment of grasslands and conservation tillage is also very critical in the South Mud Lake watershed, especially in the Rannels Ditch subwatershed.

7. Retain the C. Brown Ditch as a filtering system, i.e., do not clean or re-ditch.

8. Include South Mud Lake in an engineering study to determine what areas of residential development should be intercepted for wastewater treatment, and which methods are feasible.

9. Pastureland south of the Lake should have filterstrips and be fenced from the ditches.

10. As perhaps a more extreme method of water quality/lake restoration, lake water could be pumped from the lake and either through the marshland northeast of the lake or through the recommended constructed wetland on Rannels Ditch. The result would be filtering of nutrients suspended in the lake. Input into the marsh would be calculated to be an appropriate residence time to remove the targeted nutrients. The system could be similar to an agricultural irrigation system.

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Appendix

APPENDIX A

SYSTEM: R — RIVERINE

SUBSYSTEM: 1 — TIDAL; 2 — LOWER PERENNIAL; 3 — UPPER PERENNIAL; 4 — INTERMITTENT; 5 — UNKNOWN PERENNIAL

CLASS	RB — ROCK	UB — UNCONSOLIDATED BOTTOM	*SB — STREAMBED	AB — AQUATIC BED	RS — ROCKY SHORE	US — UNCONSOLIDATED SHORE	**EM — EMERGENT	OW — *OPEN WATER/ Unknown Bottom*
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Bedrock 2 Rubble 3 Cobble-Gravel 4 Sand 5 Mud 6 Organic 7 Vegetated	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent	

*STREAMBED is limited to TIDAL and INTERMITTENT SUBSYSTEMS, and comprises the only CLASS in the INTERMITTENT SUBSYSTEM.

**EMERGENT is limited to TIDAL and LOWER PERENNIAL SUBSYSTEMS. The remaining CLASSES are found in all SUBSYSTEMS.

SYSTEM: P — PALUSTRINE

CLASS	RB — ROCK BOTTOM	UB — UNCONSOLIDATED BOTTOM	AB — AQUATIC BED	US — UNCONSOLIDATED SHORE	ML — MOSS-LICHEN	EM — EMERGENT	SS — SCRUB-SHRUB	FO — FORESTED	OW — *OPEN WATER/ Unknown Bottom*
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	1 Moss 2 Lichen	1 Persistent 2 Nonpersistent	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 *Deciduous* 7 *Evergreen*	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 *Deciduous* 7 *Evergreen*	

SYSTEM: L — LACUSTRINE

SUBSYSTEM: 1 — LIMNETIC

CLASS	RB — ROCK BOTTOM	UB — UNCONSOLIDATED BOTTOM	AB — AQUATIC BED	OW — *OPEN WATER/ Unknown Bottom*
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	

SUBSYSTEM: 2 — LITTORAL

CLASS	RB — ROCK BOTTOM	UB — UNCONSOLIDATED BOTTOM	AB — AQUATIC BED	RS — ROCKY SHORE	US — UNCONSOLIDATED SHORE	EM — EMERGENT	OW — *OPEN WATER/ Unknown Bottom*
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent	

MODIFIERS

In order to more adequately describe wetland and deepwater habitats one or more of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy. The farmed modifier may also be applied to the ecological system.

WATER REGIME

Non-Tidal

- A Temporarily Flooded
- B Saturated
- C Seasonally Flooded
- D *Seasonally Flooded/ Well Drained*
- E *Seasonally Flooded/ Saturated*
- F Semipermanently Flooded
- G Intermittently Exposed
- H Permanently Flooded
- J Intermittently Flooded
- K Artificially Flooded
- W Intermittently Flooded/Temporary
- Y Saturated/Semipermanent/ Seasonal
- Z Intermittently Exposed/Permanent
- U *Unknown*

Tidal

- K *Artificially Flooded*
- L Subtidal
- M Irregularly Exposed
- N Regularly Flooded
- P Irregularly Flooded
- *S Temporary-Tidal
- *R Seasonal-Tidal
- *T Semipermanent-Tidal
- *V Permanent-Tidal
- U *Unknown*

*These water regimes are only used in tidally influenced, freshwater systems.

WATER CHEMISTRY

Coastal Halinity

- 1 Hyperhaline
- 2 Euhaline
- 3 Mixohaline *(Brackish)*
- 4 Polyhaline
- 5 Mesohaline
- 6 Oligohaline
- 0 Fresh

Inland Salinity

- 7 Hypersaline
- 8 Eusaline
- 9 Mixosaline
- 0 Fresh

pH Modifiers for all Fresh Water

- a Acid
- t Circumneutral
- i Alkaline

SOIL

- g Organic
- n Mineral

SPECIAL MODIFIERS

- b *Beaver*
- d *Partially Drained/Ditched*
- f Farmed
- h *Diked/Impounded*
- r Artificial Substrate
- s *Spoil*
- x Excavated

NATIONAL WETLANDS INVENTORY
draft 1984
(NYONA, SOUTH MUD LAKES AREA)

APPENDIX B

The following is a list of Federal, State and local agency contacts which may be useful in obtaining further information or permit requirements.

EPA
Wetland Protection Section
401 M Street SW
Washington, D.C. 20460
(202) 382-5043

EPA, Region V
230 S. Dearborn Street
Chicago, IL 60604
(312) 353-2079

US Army Corps of Engineers
20 Massachusetts Ave., NW
Washington, D.C. 20314
(202) 272-0169

US Army Corps of Engineers
Detroit District
P.O. Box 1027
Detroit, MI 48231
(313) 226-6773

US Fish & Wildlife Service
18th & C Streets, NW
Washington, D.C. 20240
(202) 343-4646

US Fish & Wildlife Service
Bloomington Field Office
718 N. Walnut Street
Bloomington, IN 47401
(812) 334-4267

IDNR
Division of Water
2475 Directors Row
Indianapolis, IN 46241
(317) 232-4160

IDEM
Office of Water Management
Chesapeake Building
105 South Meridian Street
Indianapolis, IN 46206
(317) 232-8476

IDNR
Div. of Soil Conservation
FLX1 Building
Purdue University
West Lafayette, IN 47907
(317) 494-8383

IDNR
Div. of Fish & Wildlife
607 State Office Building
Indianapolis, IN 46204
(317) 232-4080

Fulton County Surveyor
Courthouse
Rochester, IN 46975
(219) 223-3317

USDA-SCS, Fulton County
Baker Building
513 Main Street
Rochester, IN 46975
(219) 223-3220

Miami County Surveyor
Courthouse
Peru, IN 46970
(317) 472-3901

USDA-SCS, Miami County
1170 U.S. 24 West
Peru, IN 46970
(317) 473-6110

Earth Source Inc. (consultant)
349 Airport North Office Park
Fort Wayne, IN 46825
(219) 489-8511

APPENDIX C

Various Conservation Practices and Values, and Degree of Difficulty for Implementation

Conservation Plans	Required by the 1985 Farm Bill
Land Adequately Treated	Normal
Conservation Cropping System	Difficult
Critical Area Planting	Moderately Difficult
Crop Residue Management	Difficult
Diversions	Difficult
Farmstead Windbreak	Normal
Feedlot Windbreak	Normal
Field Windbreak	Normal
Field Border	Very Difficult
Grade Stabilization	Moderately Difficult
Grassed Waterway	Difficult
Holding Ponds & Tanks	Easy
Livestock Exclusion	Moderately Difficult
Livestock Watering Facility	Moderately Difficult
Minimum Tillage	Difficult
Pasture & Hayland Management	Difficult
Pasture & Hayland Planting	Difficult
Pond	Easy
Recreation Area Improvement	Normal
Sediment Control Basin	Difficult
Stream Channel Stabilization	Moderately to Very Difficult
Streambank Protection	Moderately Difficult
Stripcropping	Very Difficult
Surface Drains	Difficult
Terraces, Gradient	Very Difficult
Terraces, Parallel	Very Difficult
Tile Drains	Difficult
Tree Plantings	Very Difficult
Wildlife Habitat Management	Moderately Difficult
Woodland Harvesting	Moderately Difficult
Woodland Improvement	Difficult

Adapted from Final Report on the Black Creek Project; Allen County (Indiana) Soil and Water Conservation District.

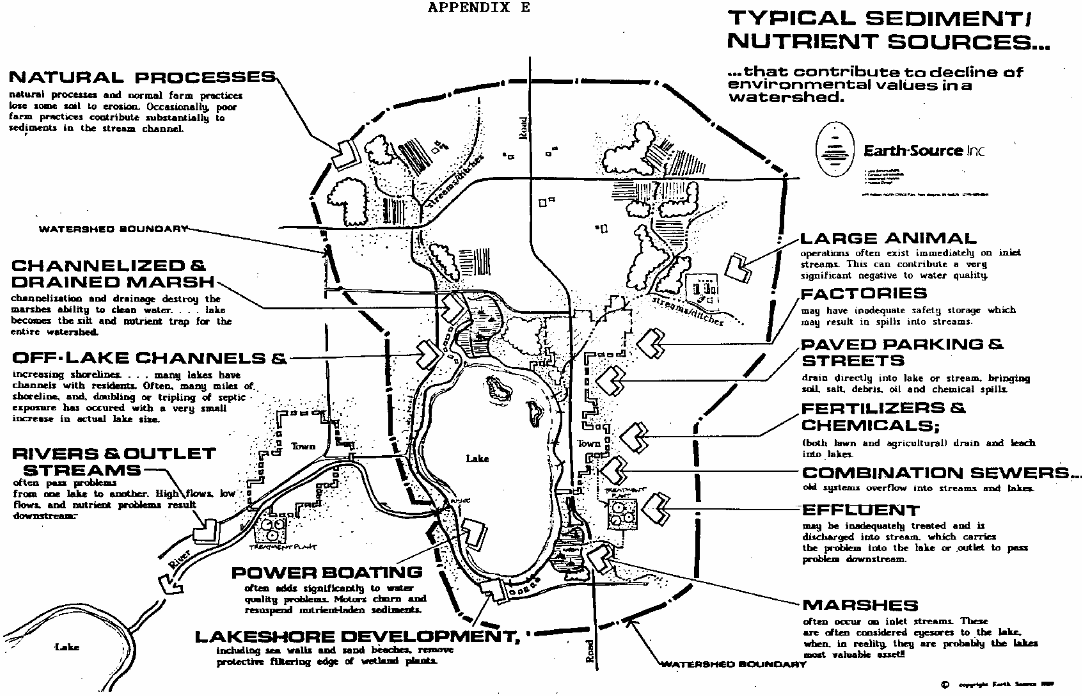
APPENDIX D

PRACTICE	EFFECTIVENESS	LONGEVITY	CONFIDENCE	APPLICABILITY	POTENTIAL NEGATIVE IMPACTS	CAPITAL COST	O&M COST
Addition of Tertiary Treatment	E	E	E	E	E	F	F
Construction of Sedimentation Basins at Inlets to Lake	G	E	G	G	G	F	F
AGRICULTURAL PRACTICES							
—Conservation Village	F-E	G	G	G	F	F	F
—Contour Farming	F-G	P	F	G	E	E	E
—Pasture Management	F-G	E	E	G	E	E	E
—Crop Rotation	F-G	G	G	G	E	E	E
—Terraces	F-G	G	G	G	E	F	G
—Animal Waste Management	E	E	E	E	E	F	F
—Grass Waterways	E	E	G	G	E	G	E
—Buffer Strips	E	E	E	E	E	G	E
—Diversion of Runoff	G	G	F-G	F	E	F	G
CONSTRUCTION CONTROLS							
—Erosion Control Ordinance	E	E	E	E	E	E	E
—Runoff Control Oridnance	E	E	E	E	E	E	E
—Field Inspections	E	E	E	E	E	E	E

Legend: E = Excellent G = Good F = Fair P = Poor

SOURCE: The Lake and Reservoir Restoration Guidance Manual, USEPA

APPENDIX E



TYPICAL SEDIMENT/ NUTRIENT SOURCES...
...that contribute to decline of environmental values in a watershed.
Earth·Source Inc
NATURAL PROCESSES
natural processes and normal farm practices lose some soil to erosion. Occasionally, poor farm practices contribute substantially to sediments in the stream channel.
WATERSHED BOUNDARY
CHANNELIZED & DRAINED MARSH
channelization and drainage destroy the marshes ability to clean water. . . . lake becomes the silt and nutrient trap for the entire watershed.
OFF-LAKE CHANNELS &
increasing shorelines . . . many lakes have channels with residents. Often, many miles of shoreline, and, doubling or tripling of septic exposure has occured with a very small increase in actual lake size.
RIVERS & OUTLET STREAMS
often pass problems from one lake to another. High flows, low flows, and nutrient problems result downstream.
POWER BOATING
often adds significantly to water quality problems. Motors churn and resuspend nutrient-laden sediments.
LAKESHORE DEVELOPMENT,
including sea walls and sand beaches, remove protective filtering edge of wetland plants.
LARGE ANIMAL
operations often exist immediately on inlet streams. This can contribute a very significant negative to water quality.
FACTORIES
may have inadequate safety storage which may result in spills into streams.
PAVED PARKING & STREETS
drain directly into lake or stream, bringing soil, salt, debris, oil and chemical spills.
FERTILIZERS & CHEMICALS;
(both lawn and agricultural) drain and leach into lakes.
COMBINATION SEWERS...
old systems overflow into streams and lakes.
EFFLUENT
may be inadequately treated and is discharged into stream, which carries the problem into the lake or outlet to pass problem downstream.
MARSHES
often occur on inlet streams. These are often considered eyesores to the lake, when, in reality, they are probably the lakes most valuable asset!!
WATERSHED BOUNDARY
Road
Road
streams/ditches
streams/ditches
Town
Town
Lake
Lake
River
TREATMENT PLANT